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ABSTRACT

This book is intended to provide basic information about energy. The first three chapters describe energy supply and demand, uses and sources, and common energy terms. The next two chapters explain environmental and biological effects of energy systems. Twelve chapters that follow outline past history and technological knowledge of the following energy sources: hydroelectricity, petroleum, natural gas, coal, nuclear fission, fission reactors, geothermal energy, solar, wind power, organic wastes, oceans, hydrogen and fuel cells, breeder reactors, and fusion reactors. The final chapter offers suggestions for energy conservation. A glossary of energy terms is found in the back of the book. Many tables, graphs and simple line drawings suitable for classroom use are included. (AJ)

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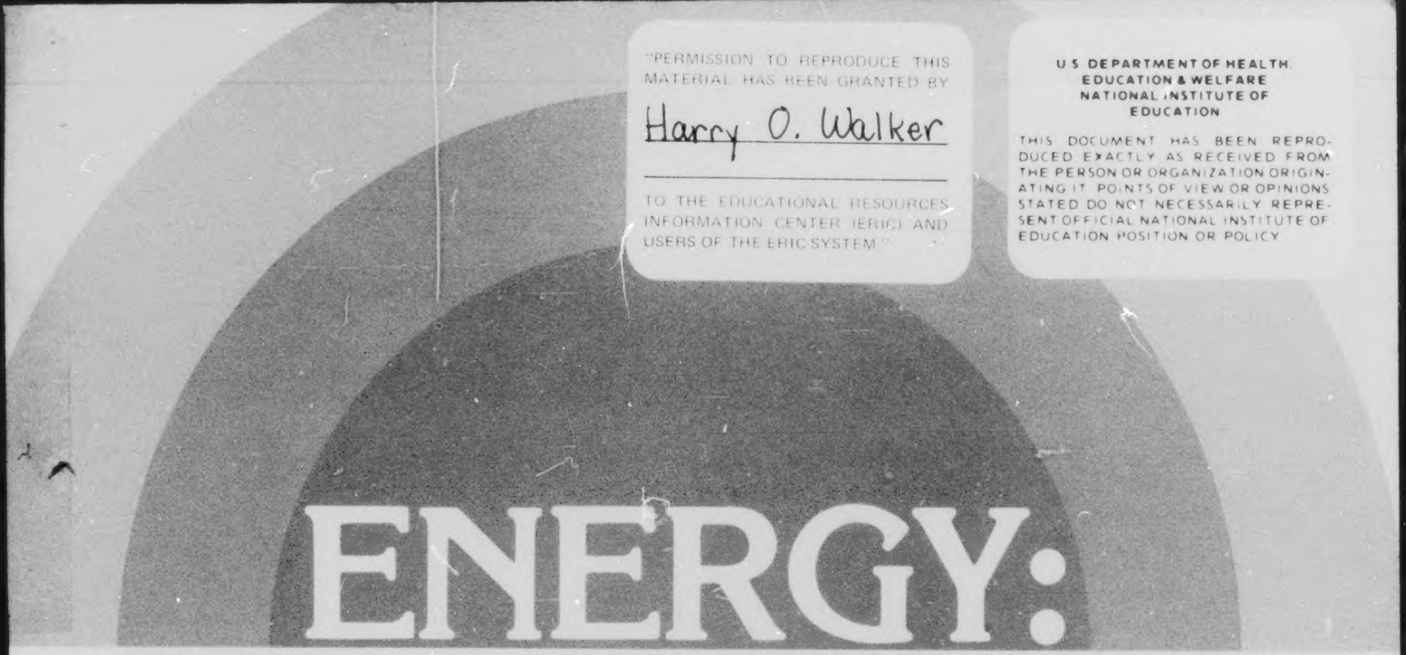

ENERGY:

Options & Issues

By Professor Harry O. Walker
University of California, Davis

ENERGY: OPTIONS AND ISSUES

Harry O. Walker
Department of Land, Air and Water Resources
University of California, Davis

March 1977

Energy: Options and Issues

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DEDICATION

This syllabus is dedicated to my wife Eleanor, our youngest daughter Laurie and the undiscovered leaders in the "younger" generation who will catalyze the synthesis of an essential, too long delayed, cohesive energy policy for the United States.

Acknowledgments

Acquisition of the data, information and experiences essential to the development of Energy: Options and Issues, could not have occurred without the assistance of a very large number of individuals and organizations. For the majority, an all encompassing "thank you" must suffice. However, the magnitude of the contributions made by a small number of persons dictates that special recognition be accorded them. Listed, on a chronology of contact basis, are those individuals to whom I direct accolades for assistance and contributions "far beyond the call of duty."

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Dr. David B. Stewart, Director of Educational Activities, Mr. Robert C. Kelso, Coordinator, School Services, and Mr. Christopher C. Newton, Coordinator - Environmental Information, Pacific Gas and Electric Company, San Francisco, California.

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Mr. Kenneth Mellor, Executive Assistant and Dr. Dan Whitney, Nuclear Engineer, Sacramento Municipal Utility District, Sacramento, California.

The Southern California Edison Company, The San Diego Light and Power Company, The Los Angeles Department of Water and Power, The California Nevada Power Company, and the Oregon Pacific and Power Company.

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Mr. Michael Hoffman, Office of the Chancellor, University of California, Davis.

With the permission of the author and in recognition of the need for developing in the general public increased awareness concerning the nature of the U. S. energy dilemma, this document is being distributed to schools and educational institutions by the Pacific Gas and Electric Company.

Energy: Options and Issues

Preface

The factors responsible for Energy: Options and Issues, are varied and not of recent origin. A "conservationist" by inclination, much of my time and effort has been directed to developing a more complete understanding of the nature of the environment which accommodates our needs. Some early impressions, many of which continue to surface, concern the fragile and inexorable interrelationships existent between the earth's resources and man's well being. As one reviews the list of resources within the U.S. which has either been exhausted or which is now precariously near the point of depletion, there develops a conviction that some unpalatable consequences of our wasteful habits will soon become apparent.

Energy, historically abundant, inexpensive and available in a variety of forms to those living in the U.S., is located at the apex of a rapidly enlarging pyramid depicting finite, depletion - prone resources. Calculations concerning energy uses in this country indicate that approximately 95% of the materials and goods produced in the U.S. result from the use of non-human energy. Assuming reasonable validity for that percentage figure, and I have encountered no challenges to the data, one can visualize some of the probable life style alterations certain to accompany significant reductions in U.S. energy availability. And reductions there will be!

Objective analysis of the ample data available concerning global energy availability versus global energy consumption yields one irrefutable conclusion, i.e., that while relatively few persons in the U.S. have thus far experienced direct consequences of energy deficiencies, the large majority of us will soon be introduced to some of the realities associated with energy shortages. Projections concerning the economic and social impacts of near-term energy deficiencies suggest that while alterations in services and activities will develop, the consequences of temporary disruptions are likely to retain manageable dimensions. Unfortunately, extrapolations concerning long-term effects, i.e., ten plus years, suggest that truly monumental redirections of life styles are in order. More than life styles are in jeopardy, however, and I urge each of you to devote periods of serious contemplation to the cumulative effects of reduced energy availability on the capabilities of this country to maintain the social, industrial and defense programs considered prudent.

Predictably, the question arises as to what can or what should, be done to develop increased lay awareness of the crucial nature of energy problems. I am of the opinion that the future of this nation rests largely with its young people. In matters relating to energy I hypothesize that if the students and instructors in the secondary schools, colleges and universities can be made aware of the role of energy and energy resources in our lives, the development of viable state and national energy policies will occur in possibly a five year period. Considering the fact that the Paley Report, which identified developing shortages in crucial resources, including petroleum and natural gas, was presented to Congress in 1952 and that during the two and one half years since the onset of the energy crisis in 1973 not even the barest essentials of a national energy policy have materialized, serious questions arise as to the interest and/or capabilities of our elected leaders to institute appropriate legislation. Given that setting, five years may seem much too brief a period for accomplishing even the initial stages of needed reform.

For those accustomed to working with young men and women of college age the reasonableness of the time limitation noted is apparent. These developing leaders, knowledgeable, concerned, capable and determined could, if provided even minimal encouragement and assistance, accelerate the deliberative-legislative processes by orders of magnitude. Having decided that the "new" generation represents the most expeditious, and perhaps the only route to energy salvation for the U.S., an outline of an appropriate course was drafted. Energy: Options and Issues, in rudimentary structure, had materialized! Discouragingly apparent was the lack of the author's understanding of certain existing and potential energy conversion procedures and the relationships of those systems to environmental quality. Correcting the deficiencies, for the greatest part, involved commitment of time for study and library research. The controversy common to nuclear energy suggested, perhaps demanded is the better term, that if the units concerning nuclear technology were to be meaningful some in-depth "hands-on" exposure and experience was essential.

An application to the Oak Ridge Associated Universities Program for a faculty-research appointment for the year 1973-74 received favorable action and a duPont fellowship appointment to the Environmental Analysis and Planning section of the Savannah River Laboratory, Aiken, South Carolina, materialized. The path was clear for what proved to be a spectacularly beneficial learning experience. The latter part of the leave period was devoted to the development of an introductory, general-education survey course for college and university students. Introduced on the UC Davis Campus Fall

Quarter 1974, course format and content have been altered to accommodate the suggestions solicited from, and offered by, students during the past two and one half years.*

The final component in this effort, after development and testing, involves the extention of factual knowledge and data to the target groups. Achievement of this last objective requires the participation of large numbers of instructors at all levels of effort. And, I might emphasize, not at some future time, but now! This year, if a small number of imaginative administrators and instructors agree to present a course similar to Energy: Options and Issues, and, if in each of the succeeding years the number of institutions offering similar courses is doubled, a "J" curve of informed, energy-aware citizens will become a reality.

What are the payoffs to institutions and instructors? First, enormous quantities of personal satisfaction resulting from having a primary role in a truly relevant activity. Secondly, involvement in one of the most important and timely topics of this decade, and third, participation in an effort which is certain to affect the happiness and well being of each of us.

If your participation remains a question, I urge each of you to study the equation $L = \frac{R \times E \times I}{P}$, where L = level of affluence, R = economic resources, E = energy consumption, I = ingenuity, and P = population. Next, alter the values of R, E, I, and P so they reflect your projections of expected changes for five, ten, twenty and thirty years into the future. Finally, having noted the effects of those changes on L, can you afford not to be directly involved?

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* Course and instructor evaluations, developed, solicited and processed by a campus service unit having no departmental affiliations, are required in the University of California system.

Introduction

The development of a national energy plan will require leadership and initiative of a caliber not heretofore conspicuous in this vital sector. Carefully monitoring both federal and state planning efforts will be the 210 million Americans whose welfare and aspirations are inextricably tied to the energy future of this country. They hold vastly differing opinions as to what America's energy future should be.

In terms of opportunities, government leadership and initiative are essential to significant energy progress. Unfortunately, the record of federal and state agencies over the past three decades, particularly since the fall of 1973, provides no great reason for elation.

To a very large extent, responses of governmental agencies and elected legislators must reflect the concerns and needs of their constituents. If we are to succeed in developing a national energy plan which assures high levels of employment, environmental protection and economic vitality, a "let George do it" philosophy cannot prevail.

Involvement without understanding is of little benefit. Before citizens can become effectively involved in energy programs, they must make the effort to become informed. They must study the energy situation in considerable depth. This volume is dedicated to that essential quest and is designed to provide basic energy information. But learning is a living process and must continue as time and circumstances change. Only through such continuing study can we participate intelligently in the debate which will take place in the individual community, state and federal basis.

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Individuals can also, by example, demonstrate individual energy saving habits. Even the most cursory glance around the shopping centers or commercial areas of our communities emphasizes that all too many people appear totally indifferent to energy conservation opportunities which seem self-evident.

Challenging and numerous avenues for involvement exist. The crucial factor, however, is involvement now -- not "later." It remains true that the central and absolutely essential ingredient in the total process is Man. Man and his productive involvement represent the key to success or to failure. And that's precisely where the individual comes in.

Get involved now -- willingly, effectively, consistently with zeal and determination. After all, there's a reason for your doing so. It's your own future you're protecting.

CHAPTER 1

ENERGY SUPPLY AND DEMAND

Until the oil embargo of 1973-1974 forced the subject upon us, few Americans gave any thought at all to where our energy comes from or to the drastic repercussions of having those energy resources denied to the world's oil-dependent industrial nations.

Although relationships between energy availability and standard of living are clear and undeniable, the United States has done very little in the three years since the energy "crisis" to solve its energy problems. Too often our newspapers, television networks and other mass media offer titilating, but technically and economically dubious scenarios for meeting the nation's energy needs.

Since 95 percent of our industrial capacity to produce the things which define a high standard of living is energy related, it becomes obvious that we must do much more than just chatter on about all the entertaining but, alas, fanciful, "solutions" that keep popping to the surface.

We must demand more than continued finger-pointing and blame-mongering. The fact is, all of us are responsible for the energy crisis. We simply have persisted in a "frontier mentality, "trusting natively that finite resources, used in ever-increasing volume will continue to be abundant at lowest cost and highest quality.

Nothing could be more self-hypnotic or dangerous. A look at global population experience warns us ominously that our energy binge cannot go on indefinitely.

From the year 1 A.D. to about 1700, global population increased very slowly; not until 1850 did it reach 1 billion. Since that time, however, the nations of the world have been involved in geometric or exponential growth, traditionally depicted by the "J curve."

When you examine the lower portion of a J curve, nothing seems to happen for quite a while. Then, suddenly, the numbers change dramatically as the bend in the J rounds, and the line assumes a very steep inclination.

To illustrate, let's consider the example of doubling thickness of paper. If you have a piece of paper about 0.1 millimeter in thickness, the early doublings will produce thicknesses of .2 mm, .4 mm, .8 mm, 1.6 mm, 3.2 mm, 6.4 mm, etc. After 8 doublings the paper is 25.6 mm. thick, or approximately 1". Twelve doublings produce a thickness of 1.3 feet and after 20 doublings, our hypothetical sheet of paper is more than 340 feet thick.

Sounds impressive, but we are still on the lower part of the J curve. I will leave it to the reader to calculate the distance between the outside pages after just 10 more doublings. This is the kind of explosive growth we are witnessing in worldwide population and energy consumption.

The global birth rate is approaching 340,000 persons a day. The daily death rate is approximately 140,000, leaving a net gain of 200,000 new inhabitants each day. Each requires a specific amount of energy to provide essential clothing, food and housing. And although the vast majority will never approach the energy use levels characteristic of today's Americans, each will have a calculable and specific impact on the global energy system.

If one can accept the United Nations' prediction of a global population nearing 6.5 billion by the year 2000, it is clear that our traditional "business as usual" philosophy cannot continue. And this is only the beginning. If the predictions are extended beyond the year 2000, urban inhabitants will outnumber the rural inhabitants for the first time.

It would be folly for us to dismiss the concept of exponential energy growth as fantasy or sci-fi. Throughout history nations have struggled, often violently, to substitute energy in various forms for human labor. Nowhere is this policy more discernible than among today's developing nations, a trend which will place even greater strain on the world's energy resources. Inevitably, the energy (J) curve must assume a signoid, or "flattened," configuration.

Clearly, business as usual cannot continue under such circumstances. The primary objective, then, is for us all to develop sufficient understanding of energy forms, energy availability, energy conversion systems, utilization and energy calculations to allow intelligent participation in the development of sound energy programs for the future. If progress is to be realized toward development of a workable energy program for our country, it is absolutely essential that our young people be both well-informed and intimately involved in the decision-making process.

Dr. Chauncey Starr, president of the Electric Power Research Institute and former dean of the School of Engineering and Applied Science at UCLA, is a leading authority on energy forms and supply. His writings are valuable guideposts in developing understandings of where we are and where we should be going.

He insists that the popular term, "energy crisis," is misleading, because it implies that emergency and immediate steps can or should be taken for corrective action. Yet, an analysis of events shows very clearly that today's energy problems developed over a great many decades and may well require an equally long period for correction. The time to begin action, however, is now.

Development of a viable energy policy for the U.S. must rest on at least four major pillars.

1. A general appreciation of the magnitude and import of the problem.
2. Coherent planning and implementation.
3. Increasing our energy supplies and undertaking reasonable, cost-effective conservation programs.
4. Achieving balance between economic and environmental objectives.

Any sound energy program must also recognize these basic, if somewhat unfamiliar, energy facts-of-life.

- The era of cheap energy is ended.
- The six percent of the world's population in the U.S. cannot continue to consume one-third of the world's available energy and mineral resources.
- The economic and political instability of some of the Mideast countries upon which we rely for a significant portion of our petroleum imports makes dependence upon those sources untenable.
- Conflicts will develop over environmental protection, regardless of the energy resources and conversion methods selected or the economic necessity demonstrated.

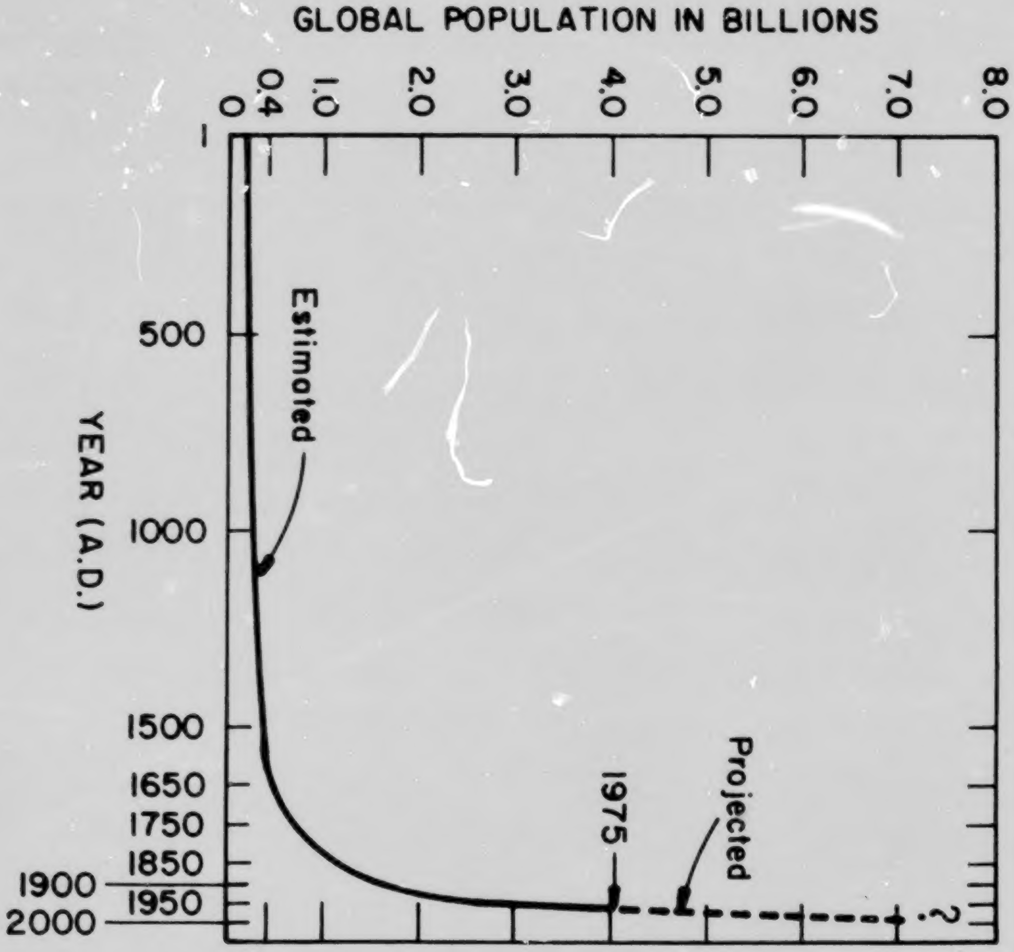
Recent experience suggests that 10 to 20 years may be required to perfect, construct and bring new energy systems into service. Is it reasonable to assume that we cannot expedite this process while maintaining appropriate safeguards?

Environmental concerns are directed, in many cases, toward air pollution. Recognizing that 80% to 90% of all atmospheric pollutants, some of which are responsible for specific adverse health effects, have as their source the combustion of fossil fuels, can we realistically regard coal as the fuel of the future? Can we place much confidence in claims made for such alternatives as wind, solar, solid waste, tides and oil shale? Have we worked at energy conservation? Can we really afford not to develop off-shore oil and natural gas reserves along the continental shelves of the U.S.?

When it comes to specific energy alternatives, the question becomes not so much whether we *can* produce geothermal or solar electricity, but rather *how much* energy we can realistically expect from each of these sources. What economic-environmental trade-offs are involved? What costs and time requirements are necessary for each of the systems whose use is contemplated? How much regulatory delay can we expect at various governmental levels?

With these questions in mind, let's now take a more detailed look at the situation we find ourselves in and the historical patterns that have led us here. Figure 1-1 shows the J-Curve of exponential growth. From an essentially steady-state population of 250 million until about 1400, global population moved quickly -- 1 billion by 1850, 2 billion in 1930, 3 billion in 1960, and so on.

Figure 1-1


GLOBAL POPULATION IN BILLIONS
0
0.4
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
YEAR (A.D.)
1
500
1000
1500
1650
1750
1850
1900
1950
2000
Estimated
1975
Projected
?

In Figure 1-2, we have a J-Curve demonstrating the increase in energy use for the same time period. At the lower left hand corner, man relied primarily on his own energy for the acquisition of food. From 400 to 800 A.D., animals were being domesticated to improve agricultural production. The introduction of water-wheels occurred about 1600, and we moved from there through slash-and-burn agriculture, steam engines, combustion engines and so forth, noting as we go, a constant strong relationship between population increases and energy consumption.

A variation on the energy consumption theme shows that total energy consumption for all activities of primitive man averaged about 2000 kilocalories a day. There was a steady increase through the hunter-gatherer period, early and advanced agriculture right on up to modern man whose energy consumption, worldwide, is 230,000 kilocalories per person per day. This represents the total energy utilized for the production of homes, electricity, transportation, air conditioning and so forth.

Figure 1-3, from the Stanford Research Institute, compares energy demand for California, the U.S. and the free world in 1973. Because California's population is small compared to total U.S. or free world population, the curve may not appear to be all that spectacular. The important thing to note, however, is that these lines are assuming an increasingly steep slope.

Figure 1-2

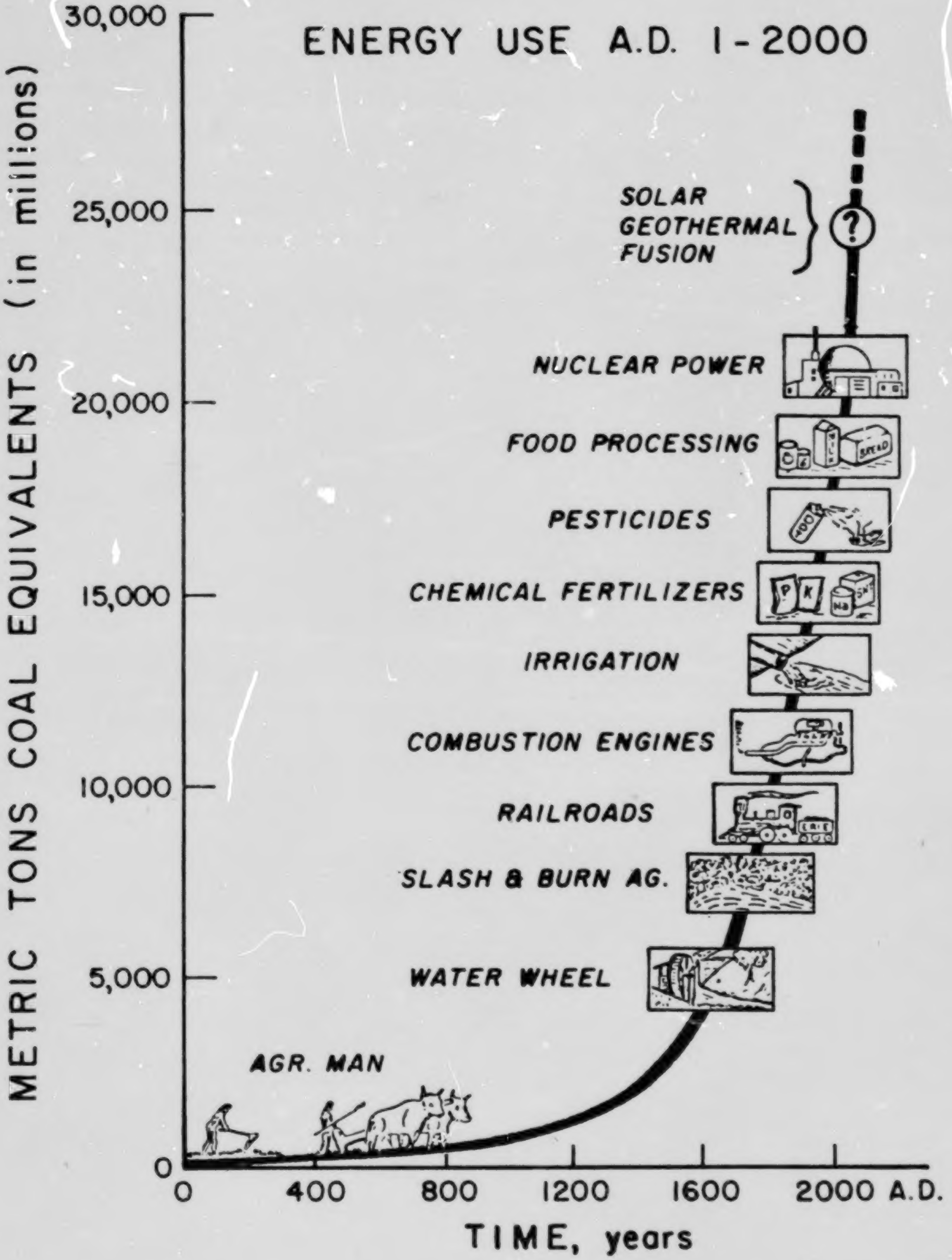
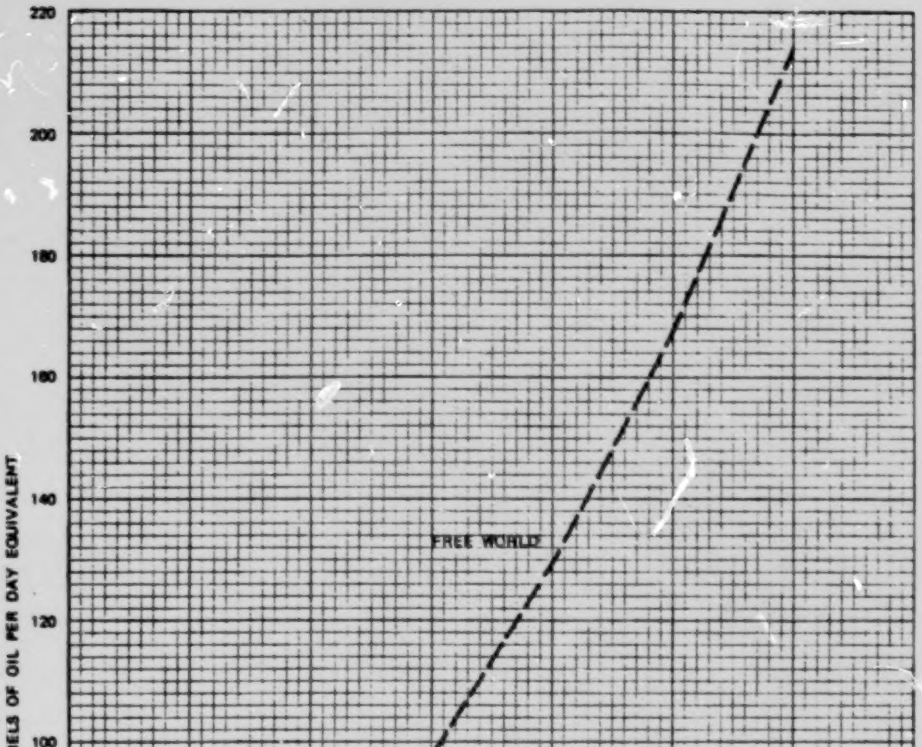

ENERGY USE A.D. 1-2000
METRIC TONS COAL EQUIVALENTS (in millions)
30,000
25,000
20,000
15,000
10,000
5,000
0
TIME, years
0
400
800
1200
1600
2000 A.D.
SOLAR
GEOTHERMAL
FUSION
?
NUCLEAR POWER
FOOD PROCESSING
PESTICIDES
CHEMICAL FERTILIZERS
IRRIGATION
COMBUSTION ENGINES
RAILROADS
SLASH & BURN AG.
WATER WHEEL
AGR. MAN

Figure 1-3

TOTAL ENERGY DEMAND IN CALIFORNIA, THE UNITED STATES, AND THE FREE WORLD, 1960-1990



SOURCE: SRI.

Energy projections are, of course, extrapolated from present and historical consumption trends. Projections for total energy use in the U.S. show an increase of nearly 240% for the period, 1960 to 1990. Even more disturbing is the increase predicted for total energy consumption in the free world. Working with 1965 - 1970 as an index, the curve increases to almost 220 billion of barrels of oil per day equivalent, an increase of around 400%!

If one considers for a moment that much of the rest of the world is industrially under-developed, and that the developing nations are eager to enjoy the material benefits that abundant energy has provided the U.S., then these projections do not seem at all unrealistic.

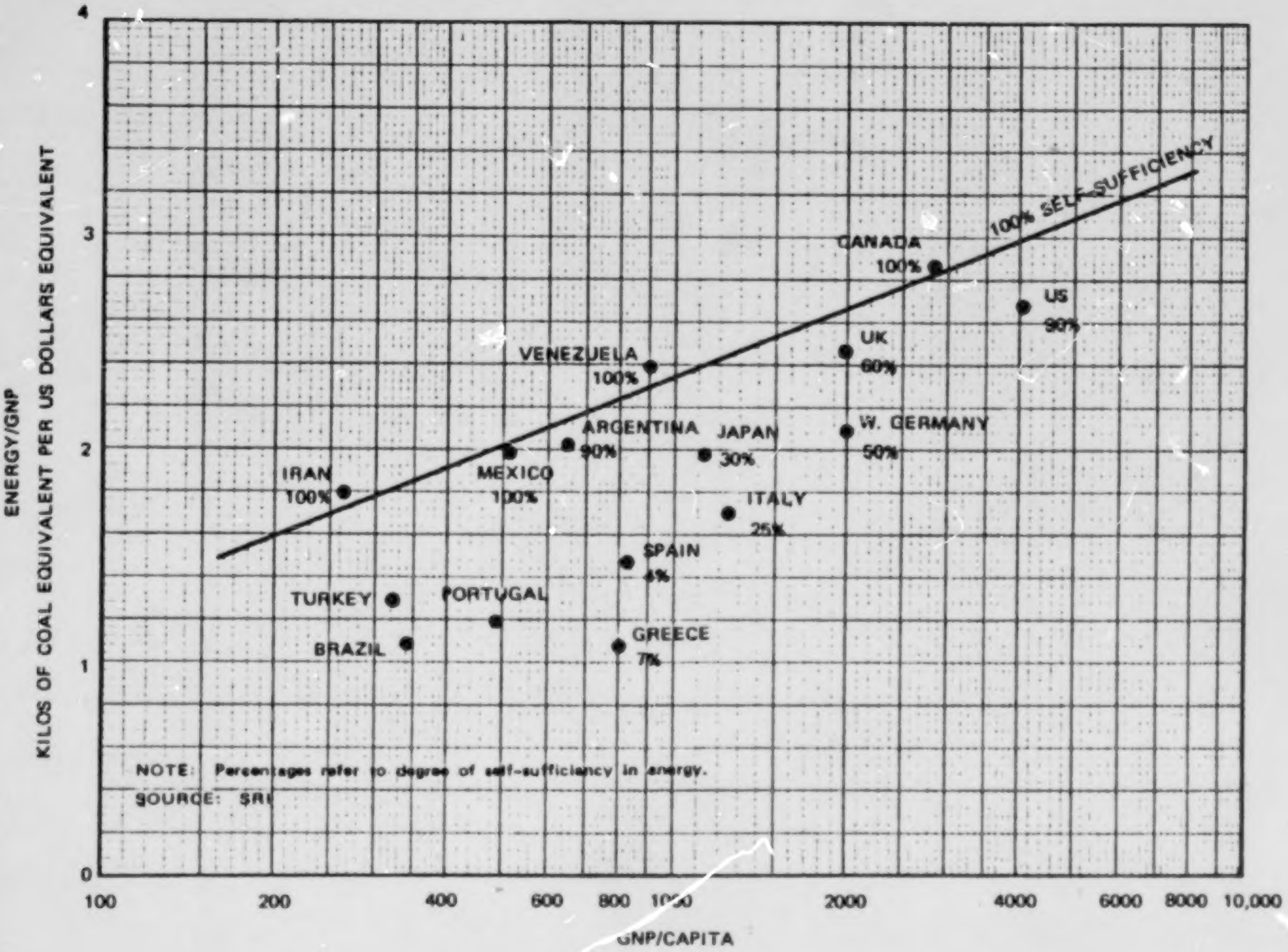
Figure 1-4 (SRI) illustrates that few countries in the world enjoy complete energy self-sufficiency. Note that only three countries are above the line: Iran, Venezuela and Canada. The U.S., on the extreme right-hand side, achieves 90%; the United Kingdom, 60%.

Such highly industrialized countries as West Germany (50%) and Japan (30%) must rely on substantial energy imports. This suggests, of course, that a nation can import much of its energy and still have a viable industrial economy. If importation were the only option available to the U.S., it would be perhaps a bit easier for us to agree quickly concerning our future energy program.

Figure 1-5 (SRI) illustrates differing levels of demand for primary energy in different regions of the world. Primary energy is used directly; the combustion of gasoline in a car engine, the burning of natural gas for home cooking and the burning of oil in an industrial boiler are examples.

Figure 1-4

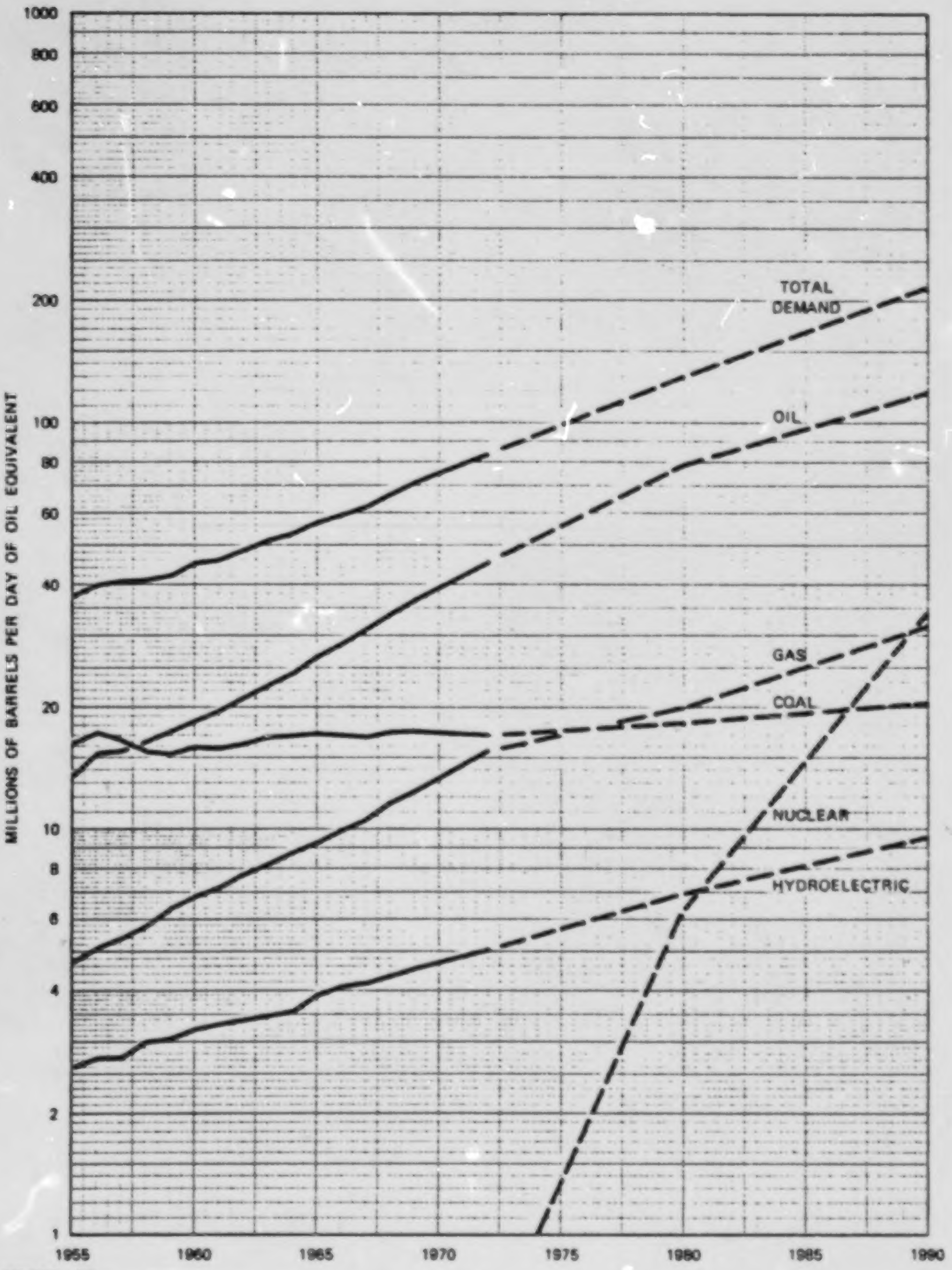
RELATIONSHIP AMONG ENERGY USE, DEGREE OF ECONOMIC DEVELOPMENT, AND SELF-SUFFICIENCY IN ENERGY, 1968



NOTE: Percentages refer to degree of self-sufficiency in energy.
SOURCE: SRI

Figure 1-5

DEMAND FOR PRIMARY ENERGY RESOURCES IN THE FREE WORLD, 1955-1990



SOURCE: SRI.

Secondary energy could be the use of oil to generate electricity which then is transmitted to consumers for direct use. The term "primary energy" and "secondary energy" should be clearly understood. Much of the energy literature uses these terms regularly, and unless the difference is appreciated, the nature of the systems being treated may not be entirely clear.

At the upper-left in Figure 1-6 (SRI) the smaller graph for primary energy consumption in the U.S. over the period, 1955 through 1990, demonstrates that for hydroelectric, coal and natural gas, the curves remain essentially constant with perhaps a minor increase for natural gas. (A caution. Their relative contribution to the total energy mix will be about the same in percentage terms. Their absolute contribution will most likely increase.)

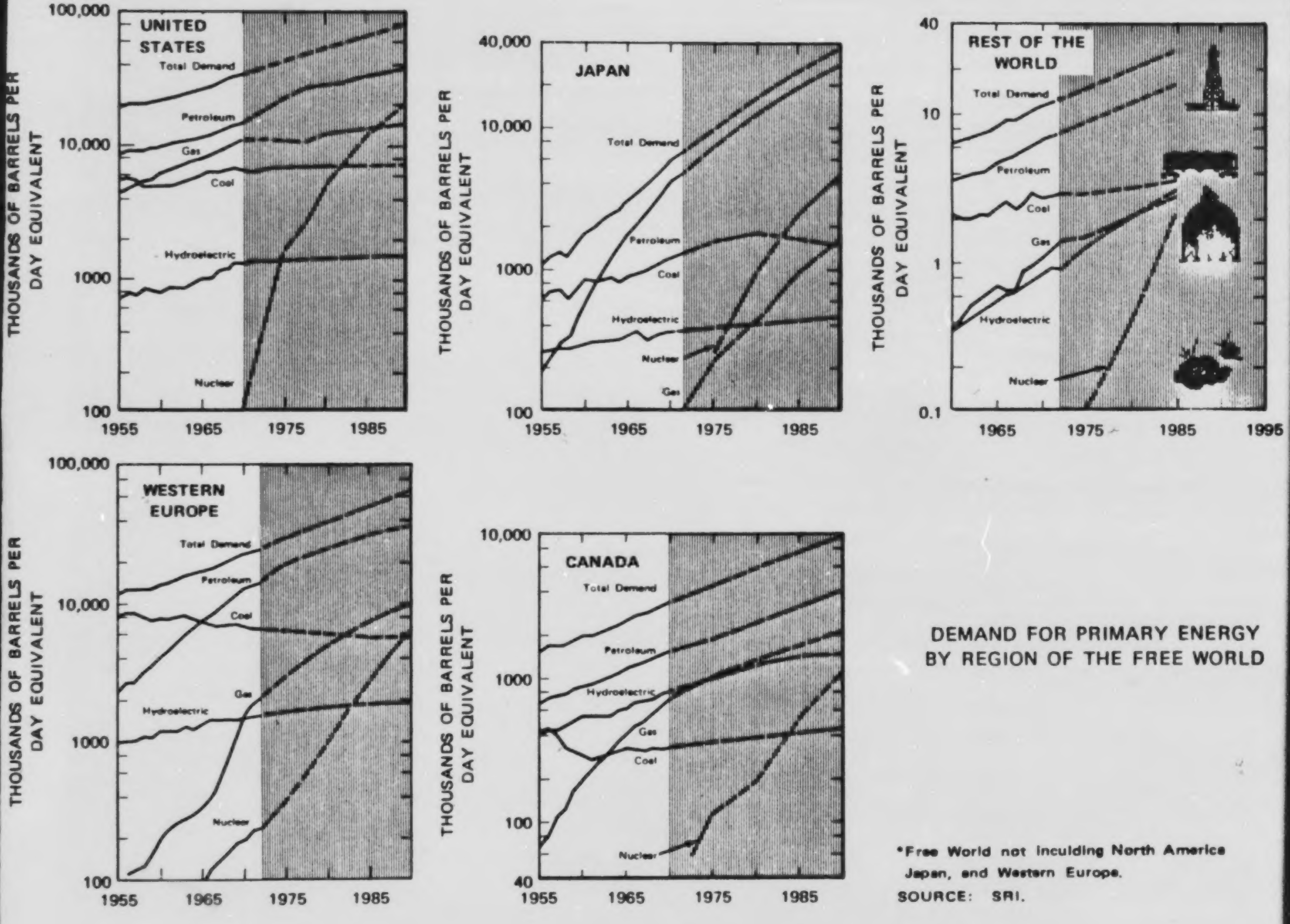
A clear percentage increase is predicted in the use of petroleum, and the nearly vertical line after 1970 for nuclear (fission) energy demonstrates the optimistic predictions being made for that particular resource.

For Japan, note that projected contributions for hydroelectric and coal are similar to the U.S. outlook, essentially constant with some minor increases. Petroleum, natural gas and nuclear energy, however, show significant increases. Recall from the previous figure that Japan provides only 30% of its energy needs from domestic sources.

The graph for Western Europe (lower left corner) shows relatively constant use of hydroelectric and coal and an increasing reliance, from 1965 through 1990, on nuclear, natural gas and petroleum. Canada exhibits an increased demand curve for all energy forms, including nuclear.

Finally, note that for the rest of the world demand for all energy resources is expected to increase substantially, with petroleum and nuclear showing the highest growth rates.

Figure 1-6



DEMAND FOR PRIMARY ENERGY BY REGION OF THE FREE WORLD

*Free World not inculding North America Japan, and Western Europe.

SOURCE: SRI.

The common denominators in all these projections are increasing reliance on nuclear, natural gas and petroleum, with less development of hydro and coal. In view of declining supplies of natural gas and petroleum, the implications of these global projections are apparent.

Figure 1-7 (SRI) demonstrates the relationship between Gross National Product (GNP) and total energy consumption in the U.S. for the period 1920-1971. On an international basis, data for any of the industrialized countries demonstrate essentially the same relationship. The U.S. enjoys the highest standard of living of any country in the world, with 90 percent of the material things we too often take for granted based on nonhuman energy.

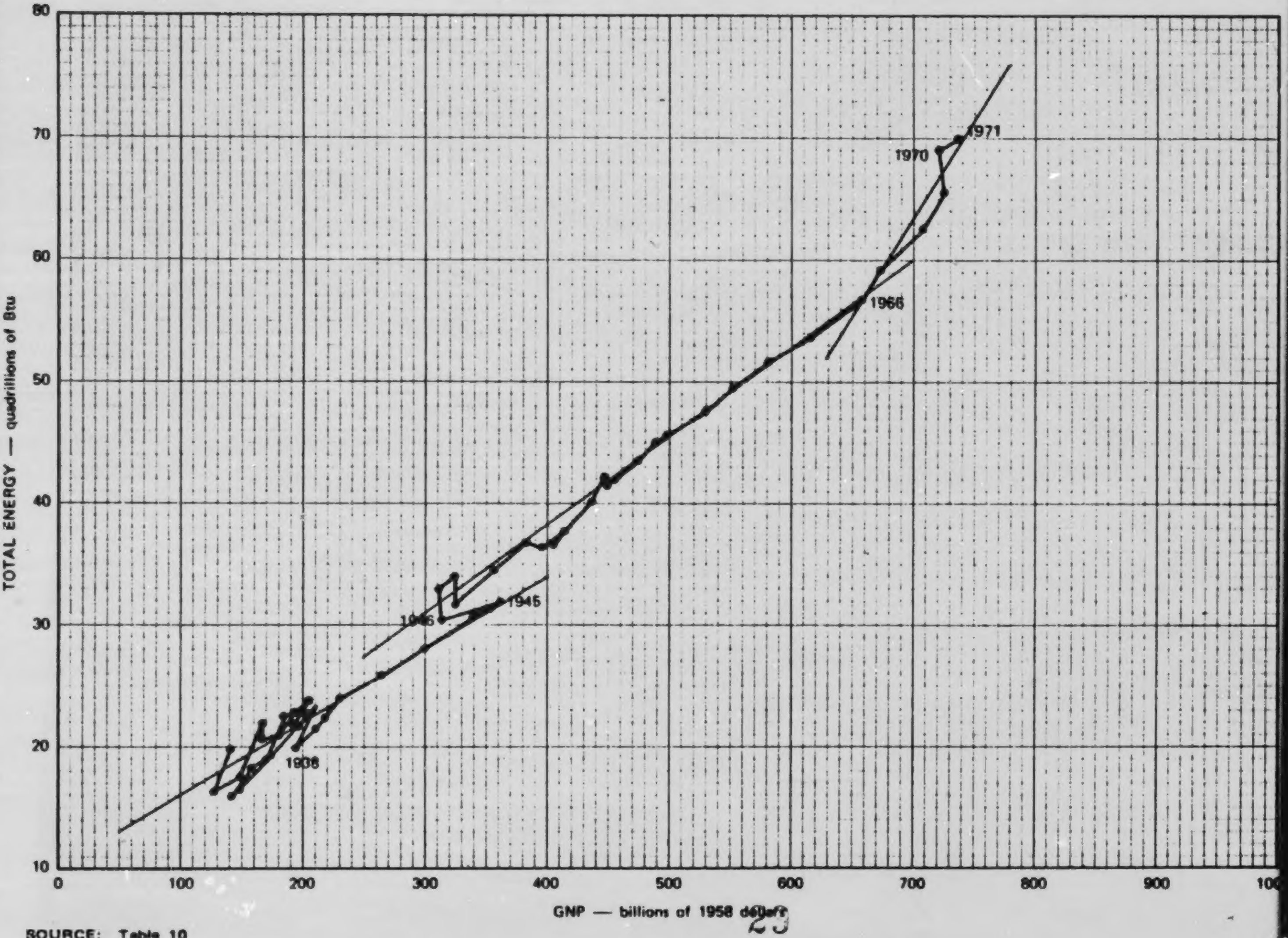
Figure 1-8 compares population and per-capita energy consumption projections in barrels of oil per day equivalent for the period 1955-1985. The impact of increased per capita energy use is apparent. The line for 1970 discloses that each of us used the equivalent of more than 1 barrel of oil per week. (All numbers are millions of barrels of oil per day equivalent.)

The next three figures were developed by the Lawrence Livermore Laboratory of the University of California. Despite an initial impression of complexity, they are quite easily interpreted.

Let's first consider energy flows and relative contributions from various fuels in the year 1950. In Figure 1-9 the figures on the far left show that coal ranked first at 13.6 million barrels of oil per day equivalent (MBO/DE), petroleum second, at 11.9 and natural gas, third at 6.1. Hydroelectric contributed only 0.4 and petroleum imports were only 1.9. As we progress from 1950 through 1990, there will be significant alterations in our reliance on the different energy forms, but bear in mind particularly the changes in imports.

Figure 1-7

RELATIONSHIP OF GROSS NATIONAL PRODUCT AND TOTAL ENERGY CONSUMPTION IN THE UNITED STATES, 1920-1971



SOURCE: Table 10

Figure 1-8

Per Capita Use of Energy

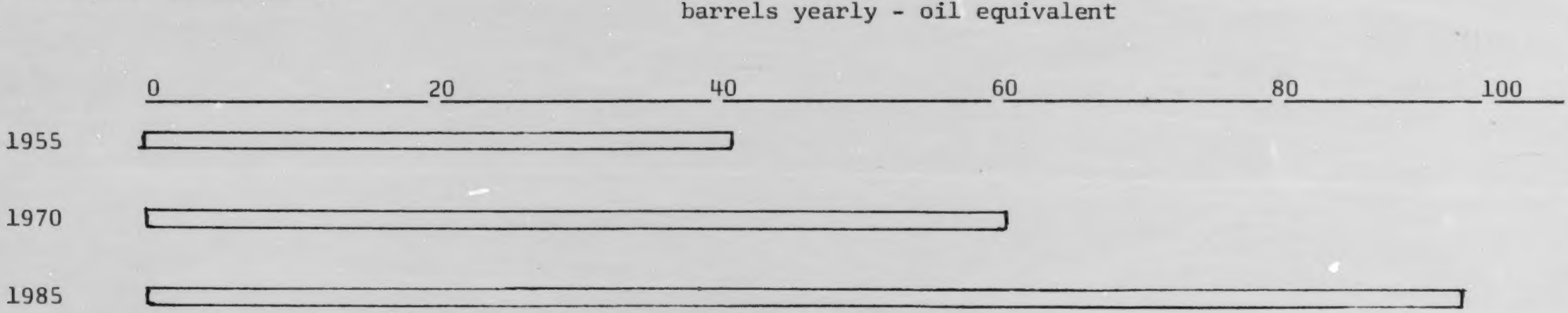
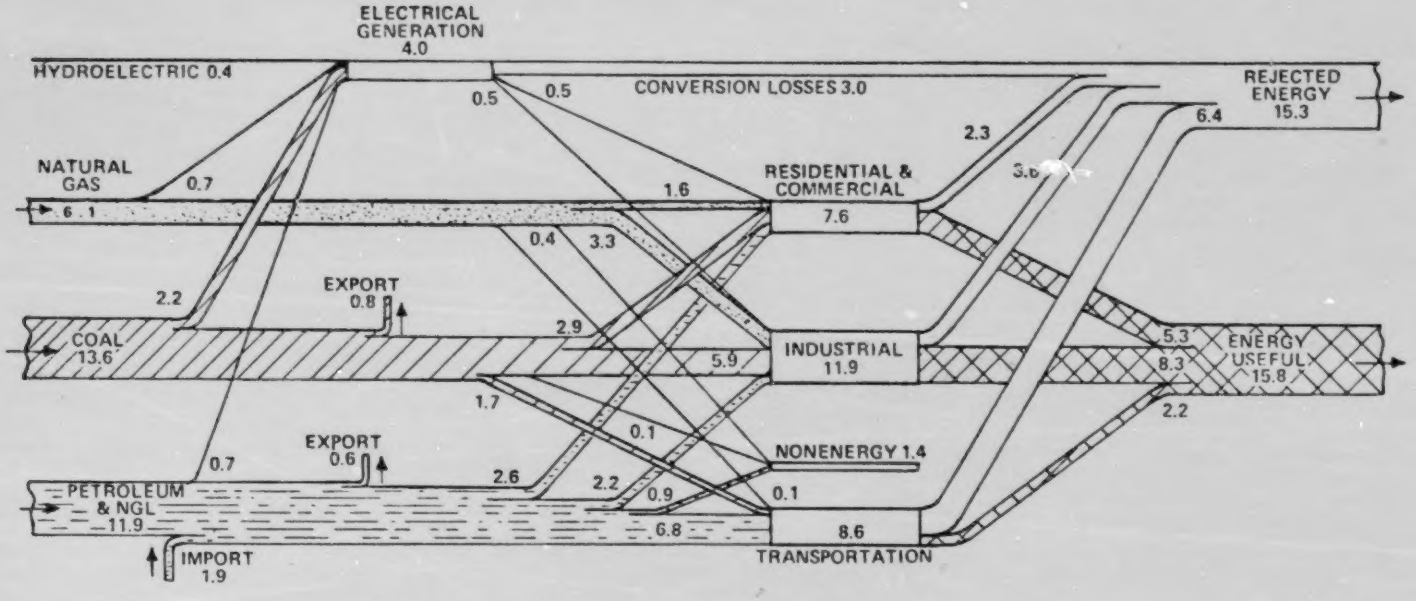


Figure 1-9


ELECTRICAL GENERATION 4.0
HYDROELECTRIC 0.4
0.5
0.5
CONVERSION LOSSES 3.0
REJECTED ENERGY 15.3
6.4
2.3
3.6
NATURAL GAS
6.1
0.7
1.6
RESIDENTIAL & COMMERCIAL
7.6
0.4
3.3
2.2
EXPORT 0.8
COAL 13.6
2.9
5.9
INDUSTRIAL 11.9
5.3
8.3
ENERGY USEFUL 15.8
2.2
1.7
0.1
EXPORT 0.6
0.7
NONENERGY 1.4
2.6
2.2
0.9
0.1
PETROLEUM & NGL 11.9
6.8
8.6
TRANSPORTATION
IMPORT 1.9

U.S. Energy Flow — 1950

All values in 10^{15} Btu (2.12×10^{15} Btu = 10^6 bbl/day oil)

Total energy consumption = 33.9×10^{15} Btu.

LAWRENCE LIVERMORE LABORATORY

Moving from left to right, the central section of the graph indicates the actual energy realized from the various fuel inputs. The right-hand side shows rejected energy at 15.3 MBO/DE and useful energy at 15.8. A quick calculation reveals that about half the energy was wasted, another useful fact to retain.

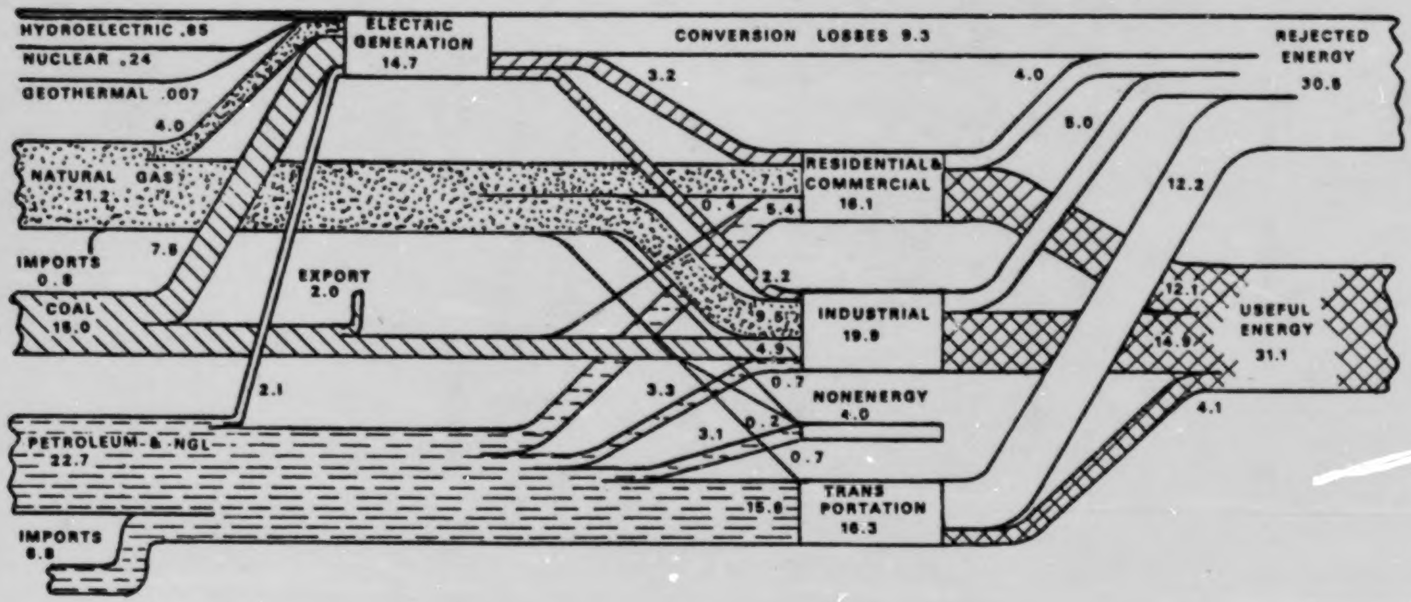
The energy flow situation for 1970 Figure 1-1C, shows a significant increase in energy imports. Petroleum is 22.7 MBO/DE; natural gas, 21.1; coal, 16; hydroelectric, .85 and, two new forms, nuclear, .24 and geothermal, .007. The conversion losses remain about the same -- rejected energy at 30.5, useful energy at 31.1. Total energy usage has doubled in the 20 years since 1950.

Figure 1-11 projects U.S. energy demand and flow for 1990. Projections, of course, can change dramatically with changes in economic conditions and international circumstances. Even so, there will likely be vast alterations in the energy flow picture for the U.S.

Petroleum imports are projected to increase to 24.1 MBO/DE, with domestic petroleum production at 29.0. Coal is estimated at 29.8; domestic natural gas 24.0; imported natural gas, 8.0; hydroelectric, 1.1 and nuclear, 32.

There is a steady increase in U.S. reliance on petroleum imports. A sharp increase occurs in the use of nuclear energy and we witness contributions from such unfamiliar energy forms as geothermal, synthetic natural gas from coal and oil from coal and shale.

Figure 1-10


HYDROELECTRIC .85
NUCLEAR .24
GEOTHERMAL .007
4.0
NATURAL GAS 21.2
IMPORTS 0.8
7.8
COAL 15.0
EXPORT 2.0
2.1
PETROLEUM & NGL 22.7
IMPORTS 6.8
ELECTRIC GENERATION 14.7
CONVERSION LOSSES 9.3
3.2
7.1
0.4
5.4
2.2
9.5
4.9
0.7
3.3
0.2
3.1
0.7
15.8
RESIDENTIAL & COMMERCIAL 16.1
INDUSTRIAL 19.9
NONENERGY 4.0
TRANS PORTATION 16.3
4.0
5.0
12.2
12.1
14.9
4.1
REJECTED ENERGY 30.6
USEFUL ENERGY 31.1

U.S. Energy Flow – 1970

All values × 10^{15} Btu (2.12×10^{15} Btu = 10^{6} bbl/day oil)

Total energy consumption = 67.5×10^{15} Btu

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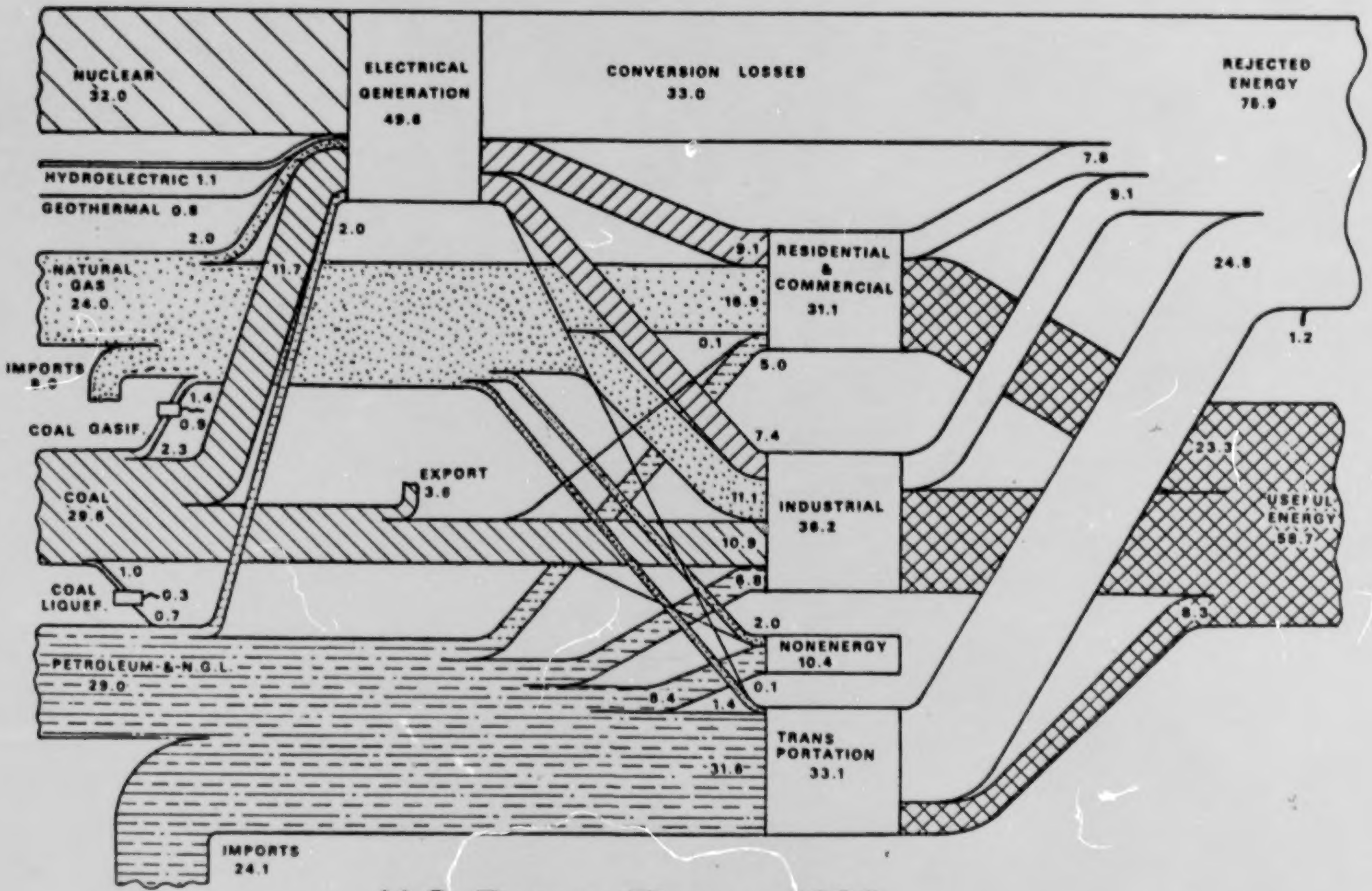
Figure 1-11


NUCLEAR
32.0
ELECTRICAL
GENERATION
49.8
CONVERSION LOSSES
33.0
REJECTED
ENERGY
75.9
HYDROELECTRIC 1.1
GEOTHERMAL 0.8
2.0
2.0
11.7
NATURAL
GAS
24.0
IMPORTS
9.0
1.4
0.9
COAL GASIF.
2.3
COAL
29.6
EXPORT
3.6
1.0
COAL
LIQUEF.
0.3
0.7
PETROLEUM & N.G.L.
29.0
IMPORTS
24.1
9.1
10.9
0.1
5.0
7.4
11.1
10.9
6.8
2.0
0.1
8.4
1.4
31.6
RESIDENTIAL
&
COMMERCIAL
31.1
INDUSTRIAL
36.2
NONENERGY
10.4
TRANS
PORTATION
33.1
7.8
9.1
24.8
1.2
23.3
USEFUL
ENERGY
58.7
8.3

U.S. Energy Flow — 1990

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Modeled after NPC Intermediate Demand Case

All values in 10^{15} Btu (2.12×10^{15} Btu = 10^6 bbl/day oil)

Total energy consumption = 148.6×10^{15} Btu

It is reasonable to assume that some other potential energy forms, such as solar energy, fuels from organic wastes, wind and tidal power could contribute to the total energy scene. However, it is particularly important to bear in mind the magnitude of projected imports of petroleum and natural gas.

Figure 1-12 (SRI) presents, in a different format, the information provided by the three previous figures. The scale on the left depicts millions of barrels of oil per day equivalent. Note that the lower line, marked "Supply," denotes the domestic energy supply capacity. The upper line is "U.S. Demand," and the substantial shaded area indicates the difference between what we have and what we should have. The choices are apparent: We can develop new energy sources. Or we can reduce demand by the amount indicated. Or we can import energy in the magnitude expressed here. Or we can achieve some reasonable synthesis among our options.

Table 1-1 lists world petroleum resources. The Persian Gulf nations clearly dominate the petroleum resource picture. U.S. reserves are rather modest, and we already import significant guantities of oil from Africa and Latin America.

Tables 1-2 and 1-3 represent U.S. petroleum usage. Assuming no significant increase in domestic production, shown to be 11.6 million barrels per day, the deficiency, in the year 1975, 1980 and 1985, becomes rather impressive. For each year since about 1970, U.S. reliance on petroleum imports has increased at the rate of about 1 million barrels per day. While California departs somewhat from the national average, it tends to parallel the national trend overall.

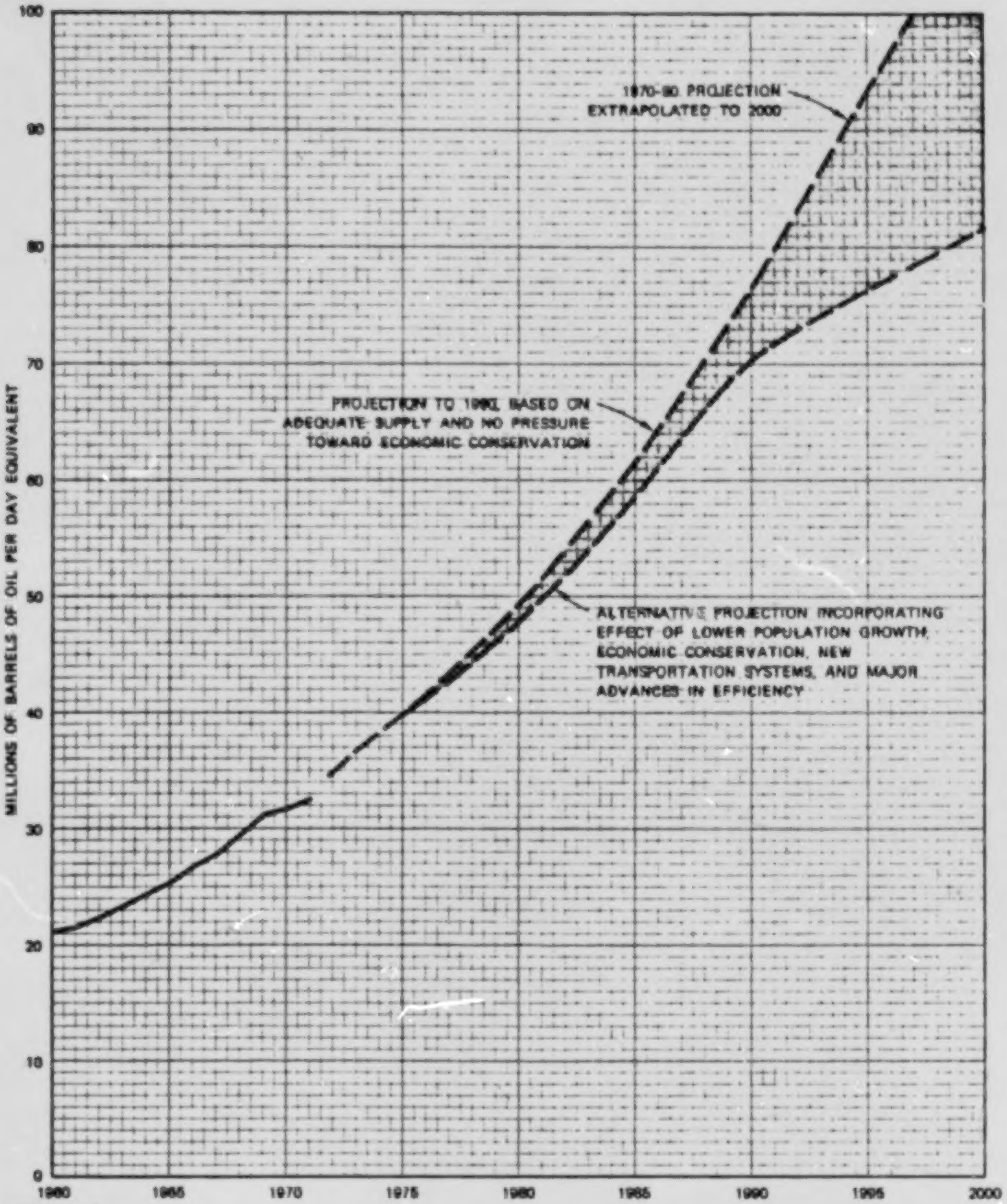

Figure 1-12

DEMAND FOR PRIMARY ENERGY IN THE UNITED STATES, 1960-2000

SOURCE: SRI.

Table 1-1

World Petroleum Resources

Geographic Location	Proved Reserves (billion barrels)	Possible Resources (billion barrels)
Middle East	345	800
Communist World	100	500
Africa	75	250
Continental Unites States	29	420-2,700
Latin America	26	225
Alaska	15	30-35
Europe	14	20
Far East	14	200
Canada	11	95

Table 1-2

Sources of Petroleum Used in the United States

Source	Million Barrels Per Day
Domestic (U.S.) Production	11.6
Western Hemishpere Imports, Primarily Canada and Venezeula	3.2
Eastern Hemishpere Imports	1.2

Table 1-3

Estimated United States Petroleum Demand

Year	Million Barrels Per Day
1972	16
1975	18
1980	22
1985	27

Hydroelectric energy continues to be a significant factor in the energy scene for California, but natural gas and oil provide the major components of energy in the state -- 49% and 40%, respectively, in 1974. Reflecting the international trend, increased reliance on nuclear fuels is projected in California over the next 25 years.

CHAPTER 2

ENERGY--

Learning the Jargon of the Trade

Any discussion of energy and its utilization involves language and concepts which are unfamiliar to most of us. Let's remember energy as being the capacity to perform work. Energy can take many forms. Human, animal, mechanical, chemical, tidal and so forth. In dealing with energy we bump into another term that needs to be defined - work.

For our purposes, work will be defined as the product of force times distance (FxD). The units involved in force and distance can take many forms, but in the U.S. we generally talk about pounds and feet and use the metric equivalents of the units involved.

There is a subtle but important distinction between work and energy expended. It is entirely possible to expend considerable quantities of energy without performing any work. Mark Twain regarded legislative bodies as the perfect proof of this principle.

All energy falls into one of two types, kinetic or potential. Kinetic energy is energy associated with motion, and the formula to remember is $E_k = 1/2\ mv^2$, where m = mass and v = velocity. Kinetic energy changes if the value for either mass or velocity is altered. Another way of expressing mass-velocity relationships is to note that two objects of equal mass can possess different kinetic energy only if their velocities are different. The reverse is also true.

The equation for E_k will come into use primarily when considering power generated by hydroelectric and thermal units. Changes in the volume of water released or height of a dam or in boiler pressures of a thermal generating unit will directly affect output levels.

The other energy form, potential, is defined in various ways, most frequently as energy of position or relative position or as stored energy. Examples of potential energy would be chemical energy contained in wood or fuel oil, electrical energy stored in a battery or the radiant (electromagnetic) energy of sunlight.

It is important to distinguish clearly the differences between kinetic and potential energy forms. Potential energy is converted into kinetic energy in many ways: nuclear power reactors, for example, convert the chemical energy (potential) contained in nuclear fuels into kinetic energy which heats water and produces steam. In calculating the efficiencies of energy conversion systems two equations are most useful. The maximum percentage of available energy that can be obtained from the conversion process in heat engines is termed Theoretical Efficiency (E_t). The equation is, $E_t = \frac{T1 - T2}{T1 \times 100}$ with temperatures expressed in degrees Celsius. Convert temperatures T_1 and T_2 to absolute units, by adding 273 to the Celsius values provided for the equation.

Efficiencies are largely a function of T1/T2 differences, a fact which assumes particular significance in assessing the efficiency penalty of environmental controls affecting internal combustion engines, furnace and waste gas temperatures, and the temperatures of the condenser cooling water available to power plants.

The second efficiency equation to be considered is Actual Efficiency (E_a) which is determined by dividing utilized energy by available energy and multiplying by 100 ($E_a = \frac{\text{Utilized E}}{\text{Available E}} \times 100$). The advantage of the second equation for efficiency determination is that it has general application rather than being confined specifically to heat engines. Additionally, the E_a equation includes the unavoidable energy losses from friction, convection and radiation (in heat engines) which are hand maidens of energy conversion processes.*

We come now to the term, "power," which imposes a time constraint upon the energy scene. Work equals force x distance, but no time is involved. Example: A person weighing 160 lbs. can climb a flight of stairs 30 ft. high and produce 4,800 foot-pounds of work. However, since no time is involved, no power is involved. If we imposed a time component, e.g., that the stairs must be climbed in 0.5 minutes, the 4,800 ft. pounds would have to be divided by 0.5, yielding 9,600 ft. lbs./minute.

Using the value 1 HP = 550 ft. lbs./sec., and the equation, $\text{power} = \frac{\text{energy expended (ft. lbs.)}}{\text{time (minutes)}}$, you can calculate your value as a prime mover. You are likely to discover that your personal "horse power" output is discouragingly low!

It's time now to examine some of the factors involved in energy conversion and to review or introduce processes by which energy is released or conversion occurs at the molecular level. There are striking and important differences in energy potential between a pound of uranium 235 and more common fuels such as coal, petroleum or natural gas.

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* See Appendix for 1st and 2nd laws of thermodynamics.

For example, one pound of U 235 can yield as much energy as 3 million tons of coal, an impressive difference! Such differences are important to bear in mind in developing a national energy program which balances the respective advantages and disadvantages of alternative energy systems. Some "tainted" energy forms possess such astonishing energy release capabilities that serious consideration must be given to their use.

Let's review briefly the structure of the atom, the fundamental building block of the universe. An atom contains a nucleus surrounded by a shell or shells of electrons.

The nucleus carries a positive electrical charge, imparted by protons, with the positive values of the protons balanced by the negative electrical charge of the electrons orbiting about the nucleus. The nucleus also contains neutrons which carry no charge but whose mass approximates that of the protons.

The reason for the vast differences in energy releases between fossil and nuclear fuels lies in the nature of the binding energies of the components of the atom.

In a home furnace or a log fireplace or a thermal power unit using natural gas or petroleum fuels, energy release occurs by a readjustment of the electrons from one shell to another in a chemical reaction external to the nucleus. The average energy yield for each reaction is approximately 10 electron volts (ev). A typical home flashlight has a rated capacity of 1.5 electron volts per cell. The energy release then from the average chemical reaction is about what you'd receive from 6 or 7 small dry-cells placed in series.

In contrast to the 10 electron volts produced in a chemical reaction such as combustion, the energy released via nuclear fission averages 8 Mev (million electron volts), an 800,000-fold increase. A rule of thumb frequently used in the literature puts this gain at 1,000,000: 1.

Let's now examine one specific element and contrast energy release levels under chemical and nuclear reactions. Since hydrogen is frequently mentioned as the possible fuel of the future, it seems appropriate to use it as our yardstick. For example, 111 grams of hydrogen (3.9) ounces + 889 grams of oxygen (31.1 ounces) under combustion conditions will produce 1 kilogram of water and 44 kilowatts of energy.

In a nuclear reaction, 111 grams of hydrogen, converted to 111 grams of helium, would produce 2.1 x 10^7 kilowatts of energy. Dividing that 2.7 x 10^7 by 44 indicates that you would have 477,273 more energy than that obtained from simple combustion procedures!

On the basis of these kinds of comparisons, it would be easy to jump to the conclusion that hydrogen is indeed the fuel of the future and that we should be setting about to harness some of its hidden talents. Despite the advantages, hydrogen presents a few problems which we'll consider in more detail in our chapter on potential fuels.

Much of the time, values involving energy releases -- Btu's, kilowatts, etc. -- will be in powers of 10, because it is much simpler to express large quantities in that fashion. In this regard, it is worthwhile to make the acquaintance of the expression, "order of magnitude." Order of magnitude simply means factoring by 10 (230 is greater than 23 by 1 order of magnitude; 230 is greater than .23 by 3 orders of magnitude). Also, it is wise to review the powers of 10, both the + and - values.

Net energy is an energy concept which has received relatively little attention, a most unfortunate snub indeed. Unless you have a positive net energy balance, whatever the energy system in question, you are spinning your wheels when it comes to solving problems associated with energy forms and uses. Indeed, many proposals being presented to the Congress and to other governmental bodies are so questionable in terms of net energy yield that efforts directed toward them are almost certain to be non-productive and in terms of national energy independence, counter-productive!

For example, recent proposals include off-shore drilling, strip mining of coal, in-situ coal gasification, nuclear stimulation of low yield natural gas deposits, fusion reactors, solar power, tidal power, shale oil, organic wastes, ocean thermal gradients, wind generators, etc. Admittedly, all should be studied. But even on the basis of presently available information, some seem far more promising that others.

Part of the difficulty is that for many of the proposed energy conversion schemes we simply do not have significant or valid data concerning relative efficiencies. Without such date we cannot develop realistic approaches to examining the various proposals. One of the first orders of business, then, is to gather sufficient background data to answer some of the basic questions concerning potential net energy yield.

By definition, net energy is the energy produced minus all of the energy required for production, transportation, mining, processing, etc. Extensive work in net energy yield has been conducted by Professor Howard Odom of the University of Florida (see Recommended Readings).

Professor Odom indicates that even at existing prices petroleum is by far our best energy buy in the net energy sense. With petoleum, 6.5 Btu's are produced for each Btu required for production and processing, a net energy yield of 6.5:1.

For strip mined coal, the net energy yield is 3:1; for nuclear fission 2:1; for solar power and fusion power 1:1, or nearly so. Professor Odom questions whether a positive net energy yield will exist at all for oil shale. And although the "hydrogen economy" has no direct bearing on net energy calculations, Professor Odom notes that if hydrogen were to serve a major role in meeting U.S. energy needs, the electrolytic dissociation processes involved would require a doubling of present U.S. electrical generating capacity. This is but one example of the complexities and interrelationships of the energy needs/solutions dilemma.

CHAPTER 3

ENERGY: USERS AND SOURCES

In previous units we have considered the concept of finite energy resources, infinite energy demand and the role of energy both in the United States and around the world. On the basis of information provided, it seems crystal clear that present energy consumption habits, particularly in the United States, cannot continue.

Given this, it is imperative that we extend understanding of the sources, uses and limitations of energy in the U.S. Without such understanding, any attempt to develop an intergrated, manageable energy program is not likely to succeed.

Our energy calculus must consider at least three factors if we are to arrive at useful solutions:

1. Possible and probably increases in population.
2. The consequences of the consumption of energy and other resources by that larger population.
3. The resources, energy, and minerals, etc., which may or may not be available.

There are approximately 1 billion people in the developed world today, i.e., North America, Europe, USSR, Australia and Japan. The two largest members of that group, the U.S. and the U.S.S.R., are increasing their population at about one percent a year. The average population increase for all the developing countries is 2.5%, with an occasional 3.4% reported. In projecting global energy consumption patterns and supply requirements, we cannot make the mistake of basing estimates on the U.S. alone.

In recent years, many well-intentioned persons have suggested that one of the obvious ways to balance the energy equation is to limit the size of the family to two children. Mathematical projections show that if the average American family decided to have two children, the U.S. postwar population surge would continue well into the 21st Century, and population probably would not stabilize until it reached about 400 million. The suggestion that we can solve a major part of the energy "crises" by this approach does not appear to hold the promise claimed by its advocates.

United Nations' figures show that each child absorbed into the U.S. economy (1968 data as a base) will consume, on maturity, an average of more than 1 million calories per year, or the equivalent of 13 metric tons of coal in energy. If one considers the global impact of population increases and increasing trends in per capita consumption of energy, something has to give -- either standards of living, size of the family or the quality of the environment. In time, perhaps all will have to adjust, but operationally, reduction in family size appears to be the solution most prominently supported.

Let's examine next each of the four major U.S. energy use categories, the recipient-participants of our energy largesse. The industrial sector accounts for some 40% of the energy utilized in the U.S. Examination of Table 3:1 discloses the types of energy uses common within industry. The question which comes quickly to mind is that since 40+% of total U.S. energy is consumed by the industrial sector, isn't that an obvious place to emphasize greater efficiency and conservation?

Table 3-1

Energy Use In The Industrial Area, 1968

Type of Use	Energy Used (Trillions of Btu)	Percent of Area Total	Percent of National Total
Process steam	10,132	40.6	16.7
Direct heat	6,929	27.8	11.5
Electric motors	4,794	19.2	7.9
Feedstock	2,202	8.8	3.6
Electrolytic processes	705	2.8	1.2
Other	198	0.8	0.3
Area Total	24,960		41.2

Data from Patterns of Energy Consumption in the United States, Office of Science and Technology, Executive Office of the President, Jan. 1972, p. 6.

As usual in the energy game, things aren't so cut-and-dried. Because industry operates on a profit basis, or hopes to, it tends to be self-policing when it comes to eliminating wasteful energy practices which make it less competitive in both U.S. and overseas markets. Certainly the "energy crisis" that developed in late 1973 demonstrated to industry that even greater energy savings were possible, and significant reduction in energy consumption rates, have already been realized. Many observers believe that the industrial sector has furnished the best example of energy conservation and improved efficiency.

The second largest user of energy nationally is the transportation category which consumes 24-25% of our energy. Of that total, 99% is represented by fuel, with the remainder devoted to the manufacture of lubricants. Slightly more than 50% of that fuel is consumed by private transportation. A bit later, as each of these categories is examined in more detail, the appropriateness of considering the transportation sector as a primary candidate for energy conservation and increased energy efficiency will become apparent.

The third and fourth categories, residential and commerical, are approximately equal in terms of total consumption, 18 and 19% respectively. The energy used in residences goes toward such ends as space heating, air conditioning, lighting, heating water for showers and baths, space cooling and cooking. Space heating and water heating account for about 72% of residential energy requirements.

Commercial energy use contributes to such activities as retailing, wholesaling, banking, providing food and accommodations and myriad other services. The largest energy use in both the residential and commercial categories is in space heating and air-conditioning, which account for some 60% of total energy consumption in those categories.

Let's now take a closer look at the pay-offs we might expect from altered (or lowered) energy consumption patterns in the transportation, residential and, to a lesser extent, the commercial sectors. We'll consider only strategies which are readily available. Transportation, it will be recalled, uses about 25% of all U.S. energy. In 1972, automobiles, from their manufacture to the junk heap, used 13% of U.S. energy resources. Transportation is of great interest for two reasons:

1. A significant part of the general energy reserves are utilized in this category. That factor alone make transportation an obvious conservation candidate.
2. Transportation, particularly the use of the automobile by individuals, has a major impact on environmental quality. (The role of the internal combustion engine in the production of oxides of nitrogen and sulfur will be considered in a later section, but it will suffice now to say that internal combustion engines are the primary contributors of many pollutants which scientists believe to be extremely hazardous.)

Vehicle fuel consumption is influenced primarily by two factors:

1. Gross vehicle weight and engine size.
2. Driving habits.

If one considers that the "average" automobile requires approximately 2.5 Btu's per pound per vehicle mile, a 4,000-pound automobile driven 10,000 miles per year, would require 100,000,000 Btu's per year (2.5 x 4,000 lbs. x 10,000 miles). Gasoline contains 122,000 Btu/gallon; thus the average U.S. vehicle consumes about 820 gallons of fuel annually.

To calculate the approximate mileage that can be expected from a vehicle of a given engine displacement, use the equation, mileage (M) = 230 over the square root of the displacement of the engine in cubic inches (one cubic inch equals approximately 13 cubic centimeters). Mileage = $\frac{230}{cid}$ Compare a large vehicle such as a Cadillac or Chrysler, a medium size vehicle -- Ford, Chevy or Plymouth -- and a smaller make such as a Renault or a Volkswagen. While the equations are not as precise as they might be, in terms of prediction values they do demonstrate that one immediate, and effective, way to reduce energy requirements for personal transportation is to reduce automobile weight and engine size.

The residential sector uses roughly 19% of all U.S. energy. Of that value, space heating requires about 55%; water heating, 15%; refrigeration, 6%; cooking, ± 5%. Air-conditioning, which consumes 4%, is increasing at 16% to 18% a year, the largest growth in any of the residential categories noted. Lighting is a fairly modest requirement at 3.5% per year. (See Table 3-2)

The residential sector, similar to transportation, offers both immediate and long-term potential for energy conservation. Two fairly obvious approaches promise excellent energy reductions for residential structures. The first is directed toward such improvements as insulation, weather stripping, fluorescent lights and thermally insulated windows. The second category involves introduction of solar and wind systems for supplemental heating and cooling, water heating and swimming pool heating.

Small things can make big differences. For example, assume that the traditional "comfort zone" of a residence is 70°F and the outside temperature is 55°F, yielding a temperature difference of 15°F. Lowering the thermostat

Table 3-2

Energy Use In The Residential Area, 1986

Type of Use	Energy Used (Trillions of Btu)	Percent of Area Total	Percent of National Total
Space heating	6,675	57.5	11.0
Water heating	1,736	14.9	2.9
Refrigeration	692	6.0	1.1
Cooking	637	5.5	1.1
Air conditioning	427	3.7	0.7
Lighting	412	3.5	0.7
Television operation	352	3.0	0.6
Food freezing	220	1.9	0.4
Clothes drying	208	1.8	0.3
Clothes washing	41	0.4	0.1
Dish washing	36	0.3	0.1
Other	180	1.5	0.3
Area Total	11,616		19.2

Data from Patterns of Energy Consumption in the United States, Office of Science and Technology, Executive Office of the President, Jan. 1972, pp. 38, 62.

2°F to 68°F drops the temperature differential from 15°F to 13°F. Since heat requirement is a function of a temperature difference, 13/15 = .87 = a 13% reduction in energy use.

The final category for discussion is the commercial sector which uses nearly one-fifth of total U.S. energy (See A.I.A. report and others.) Since energy use within this area is similar to that of the residential component, reductions can be achieved thru similar measures.

SOURCES OF ENERGY

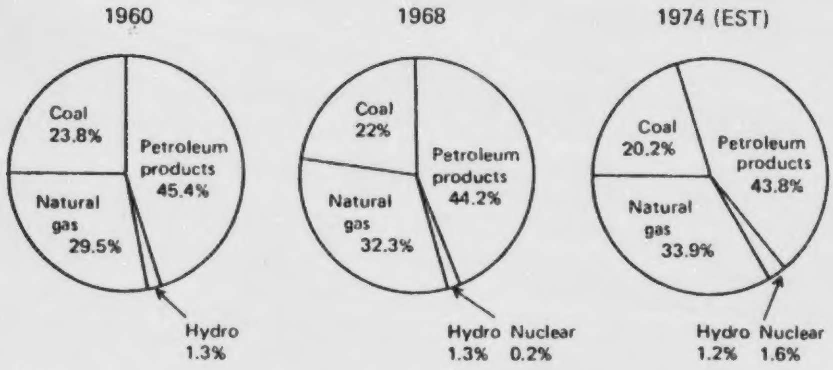
Having reviewed U.S. energy consumption by categories, it's now appropriate to examine the primary sources from which this energy comes. Figure 3-1 shows heavy present reliance on fossil fuels. In 1974-75, petroleum products provided 44% of energy needs in the U.S. natural gas, 34%; coal, 20%; hydroelectric and nuclear, about 2%.

Table 3-3 shows major end-use sectors for energy resources. Most of our coal is used by industry, while some 54% of our petroleum goes into transportation. At this time there really is no ready substitute for petroleum in transportation.

ENERGY PRODUCTION BY SOURCES (Estimates)	GROWTH RATES 1960-70 DATA BASE FIGURES (% per annum)
Petroleum - 44%	Petroleum - 4%
Natural gas - 34%	Natural Gas - 6%
Coal - 20%	Coal - 3%
Hydro and Nuclear combined - 2%	

As the chart above demonstrates, since 1960, a period of declining availability, the U.S. has rapidly increased its use of petroleum and natural gas. Dr. M. King Hubbard, a leading authority on energy resources worldwide,

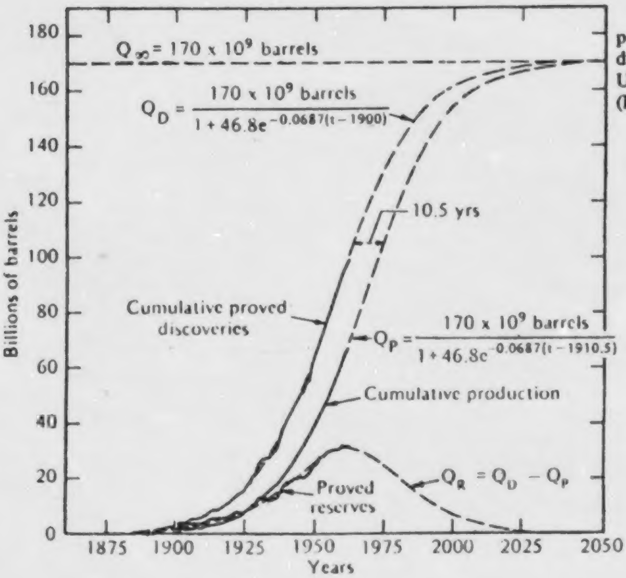
Figure 3-1



Energy Production by Source

Data for 1960 and 1968 from *Patterns of Energy Consumption in the United States*, Office of Science and Technology, Executive Office of the President, Jan. 1972, p. 22 (1974 data calculated from 1968 data and growth rates given in text, p. 41).

Figure 3-2



Curves of cumulative proved discoveries, cumulative production and proved reserves of United States crude oil as of 1962 (Hubbert, 1962, Figure 27).

Table 3-3

Energy Distribution Among Use Areas

Energy Source and Use Area	Energy Used (Trillions of Btu)			Percent of Source Energy Use In the Area
	Direct	Indirect	Total	
Coal				
Industrial	5,616	3,215	8,831	66.3
Transportation	12	29	41	0.3
Residential	-	2,188	2,188	16.4
Commercial	568	1,698	2,266	17.0
Total	6,196	7,130	13,326	
Petroleum				
Industrial	4,474	533	5,007	18.7
Transportation	14,513	5	14,518	54.3
Residential	3,192	362	3,554	13.3
Commercial	3,389	281	3,670	13.7
Total	25,568	1,181	26,749	
Natural gas				
Industrial	9,258	1,465	10,723	54.9
Transportation	610	10	620	3.2
Residential	4,606	996	5,572	28.5
Commercial	1,845	774	2,619	13.4
Total	16,319	3,245	19,534	
Hydroelectricity				
Industrial	-	341	341	45.0
Transportation	-	4	4	0.5
Residential	-	232	232	30.6
Commercial	-	180	180	23.8
Total	-	757	757	
Nuclear electricity				
Industrial	-	58	58	44.6
Transportation	-	1	1	0.8
Residential	-	40	40	30.8
Commercial	-	31	31	23.8
Total	-	130	130	
Grand Total	48,083	12,443	60,526	

Data from Patterns of Energy Consumption in the United States, Office of Science and Technology, Executive Office of the President, Jan. 1972, pp. 26-30.

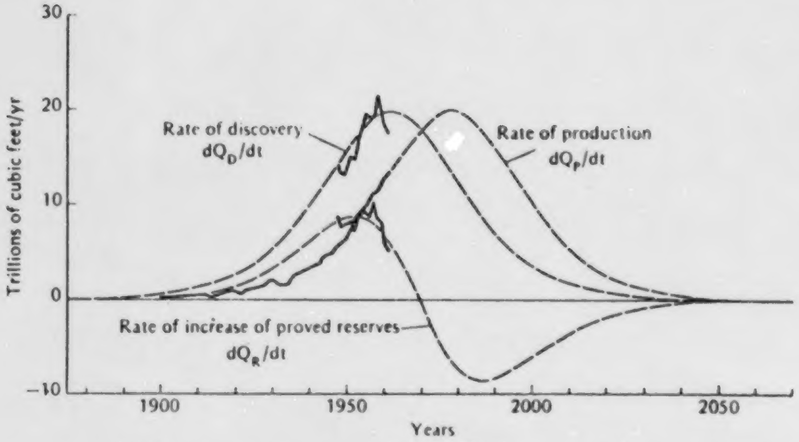
estimates that U.S. coal is in relatively good supply and should last from 400 to 600 years. Coal is available in large quantities in the U.S., Russia and China and should provide energy well into the foreseeable future.

U.S. domestic petroleum production peaked in 1970 and has declined even as the nation's reliance on petroleum imports has increased by some 1 million barrels per day per year. Figure 3-2, marks the year 2025 as that point when we will reach essentially zero petroleum production. The predicted production peak for domestic natural gas was 1977.

Actually, on the basis of existing data, it appears that the U.S. natural gas production peaked in 1974-75, Figure 3-3, with the peak for California natural gas occurring in 1968. Hubbard concludes that by 2050 there will be no domestic commercial supplies of natural gas, Figure 3-4. Increasing reference is made to Alaska's providing a major input to U.S. natural gas supplies.

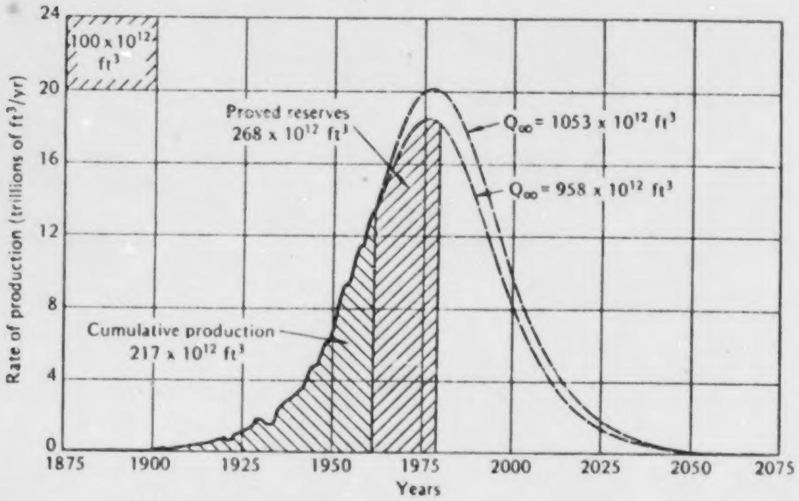
Current estimates suggest that, even if fully developed, natural gas from Alaska's north slope would meet total U.S. natural gas needs for only about 3 years. Alaskan natural gas to be available with the completion of facilities will, on the basis of 1976 data, accommodate approximately 12-15% of the annual U.S. demand for a period of 20 to 30 years. Hydroelectric power presently provides some 4% of the electrical energy consumed in the United States. Projections suggest that even with the addition of new generating facilities, increasing demand for electrical energy will limit the hydro contribution to no more than 4 percent, Figure 3-5. Nuclear, presently contributing something slightly less than 2% has a clouded future with expanded use -- dependent upon solution of a number of political, social, economic and technical factors.

Figure 3-3



1962 estimates of the dates of the peak of rate of proved discovery, rate of production, and proved reserves of United States natural gas (Hubbert, 1962, Figure 46).

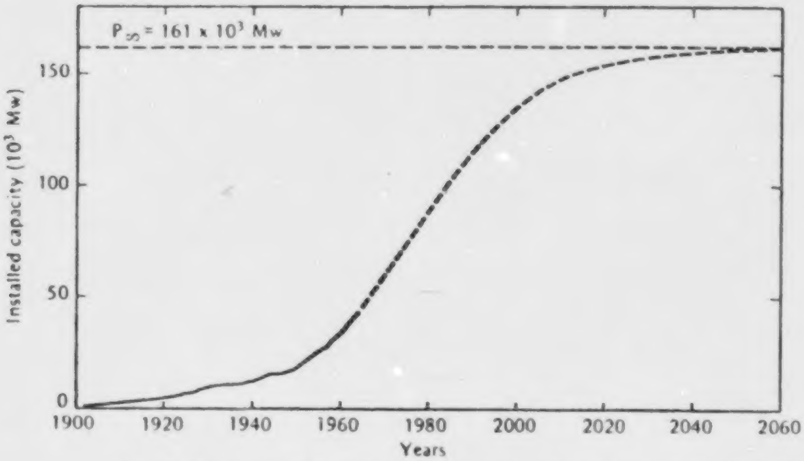
Figure 3-4



1962 estimates of ultimate amount of natural gas to be produced in conterminous United States, and estimates of date of peak production rate (Hubbert, 1962, Figure 47).

A point to emphasize is that from 95 to 96% of total U.S. energy needs are now being met by fossil fuels, two of which, petroleum and natural gas, are in chronically short supply. Coal, which constitutes the nation's major energy back-up is available in large quantities but possesses many undesirable characteristics which will have to be abated before coal can be used on a more widespread basis. Clearly, some changes are in order. It certainly appears that we should be making better use of the breathing period now available to us to set about the task of developing a workable energy policy.

Figure 3-5



. Installed and potential hydroelectric-power capacity of the United States (Hubbert, 1969, Figure 8.28).

CHAPTER 4

THE ENVIRONMENTAL EFFECTS OF THERMAL AND HYDROELECTRIC GENERATING UNITS

Discussions concerning the environmental effects of power generating units inevitably encompass consideration of the effects of waste heat discharge, altered water flows and temperatures on adjacent biota. Although the consequences of introducing oxides of nitrogen and sulphur, carbon monoxide, hydrocarbons and particulates into the atmoshpere may be less apparent, alteration of the physical environment itself does occur.

What really is meant or intended, by the various terms and expressions used? Earlier the term "thermal input" rather than the most frequently used term, "thermal pollution," was used. This is a minor but important distinction, because any attempt to deal objectively and analytically with environmental issues demands avoidance of terms and statements which are imprecise, pejorative, or unsupported by the facts. For example, in some specific cases, waste heat can produce desirable effects upon aquatic environments. This may seem a small point, but it does convey the concept that neutrality is required when discussing environmental effects of energy conversion systems.

Let's now examine the question of how thermal inputs from electric generating plants come about. One of the laws of thermodynamics tells us that no energy conversion system is 100% efficient. Thermal electric plants using the fossil fuels, coal, oil and natural gas, achieve an efficiency of about 40% overall. Nuclear units are about 30 to 35% efficient.

Obviously, with efficiencies of 30% to 40%, large quantities of energy are not used productively. For example, a modern, highly efficient plant burning 1,000 barrels of petroleum per hour, rejects about 0.60 x 1,000 x 5,800,000 (Btu's/bbl.) of its potentially useful energy.

After steam passes through a turbine, it is condensed in a unit which utilizes cool, external water in the process. Typically, this water comes from a river, a lake, the ocean or, in some cases, a reservoir used exclusively for cooling. Some day rejected condenser heat may be used advantageously, but for the present, technical and economic barriers preclude waste heat utilization.

Let's now examine some of the more immediate but obscure effects of increased temperatures on water itself. An increase in the temperature of a given body of water decreases its capacity to hold dissolved oxygen. As the capability to retain dissolved oxygen decreases, moreover, increased temperature accelerates the use of oxygen by aquatic organisms. We are then working at cross-purposes.

Also, chemicals in the water have their effectiveness, or chemical reactivity, accelerated by increased temperatures. Finally, elevated temperatures, particularly in lakes or slowly moving rivers, tend to form stratified layers of water with differing temperatures. Numerous aquatic organisms are adversely affected by such environmental alterations.

Alteration of the temperature of the water affects aquatic biota in other ways. Perhaps the most apparent is an acceleration of the eutrophication process. There may also be alterations in the migration patterns of anadromous species such as steelhead and salmon. Decreased survival rates for young fish may occur, because these are forced to traverse the areas of elevated temperature or because they may be required to adjust unfavorably to increased general temperatures.

It's important to note here that considerable evidence exists to suggest that in some inland lakes and off-shore areas, increased fish populations appear to result from thermal inputs. In fact, studies from Europe and Asia suggest that the heated effluent can be introduced in shell fish production and contribute to growth rates as much as 50% above those experienced under natural conditions.

The Water Quality Act of 1972 allows states to establish their own thermal input standards, subject to approval by the Environmental Protection Agency (EPA). California allows no more than a 4°F rise in water temperature over the ambient condition at coastal locations, mandating the use of cooling towers at new inland power plant sites.

Accepting the need for water to cool the condensers as an integral part of the power generation process, let's examine the mechanisms used to dispose waste heat into the environment and the influence of cooling water temperatures on power plant efficiencies.

The traditional system for cooling condensers is termed, "once-through." As the name suggests, it's a rather simplified method for routing water from streams, large inland bodies of water or the ocean into the condensers and then returning the water to the source from which it was drawn.

Once through cooling systems present many advantages. The systems are, from an engineering standpoint, simple, relatively inexpensive to construct and maintain, and with appropriate safeguards, they offer minimum hazard to aquatic organisms.

An appreciation of the volume of cooling water required in a once-through cooling process can be gained by noting that about .01 gallons of water per second are required for each kilowatt of power produced for a temperature rise of 15°F. By that standard, a 500-megawatt station would require a constant cooling water flow of nearly 5,000 gallons per second. If the temperature of the returned water were to be lowered to 5°F rather than 15° noted, the water flow would have to be increased threefold, i.e., to 15,000 gallons of water per second.

Despite the engineering and operational cost advantages of once-through cooling, a trend toward prohibiting power plant siting in coastal or estuarine areas has forced the consideration of alternative cooling methods. In the last decade, cooling towers -- large, parabolic, monolithic, cement structures -- have appeared with increasing frequency in various parts of the U.S.

Cooling towers may be "wet" or "dry," and each type possesses certain advantage and/or disadvantages in terms of construction costs, power rates for consumers and environmental impact. The terms, "wet" and "dry," derive from whether water vapor is released to the environment during the cooling cycle. Wet cooling towers rely upon evaporation as the primary means for cooling, a disadvantage in that the water evaporated is lost as far as irrigation or domestic purposes are concerned. A rule of thumb for calculating evaporation loses from wet cooling towers is about 2% of the water moved through the units during a given period.

The dry cooling tower works in much the same way as an automobile radiator. Water is pumped through the cooling unit, which in actuality is a very large heat exchanger, with the excess heat vented to the atmosphere itself. No water is lost through evaporation, but construction and operating costs are significantly greater than "wet" type cooling units.

Cooling ponds of 1,000 to 2,000 acres in surface area are a third type of power plant "heat sink." As might be expected, the considerable cost in constructing the ponds and large losses through evaporation and seepage make this a limited alternative.

In considering the choices available to utilities and their customers for the cooling of condenser water, Dr. Barry Commoner has said: "There is no such thing as a free lunch. In any event, the consumer pays." Dr. Commoner's view is borne out in any evaluation of construction and operational costs for the types of cooling systems discussed.

A 1971 Scientific American article entitled, "Cooling Towers" suggests that if once-through cooling represents a base cost of 1.0, a cooling pond increases cost by about 1.3, a natural draft wet tower by about 1.8, and a natural draft dry tower by about 6.2. However, it's likely that support can be developed for each of these cooling procedures where circumstances dictate the greater desirability of one type over the others.

Since once-through cooling involves a significant reduction in consumptive water use, the use of cooling towers introduces at least two factors worthy of consideration. The first relates to the fact that water is lost in the cooling process, i.e., about 2% of the cooling flow rate is evaporated. The two natural draft wet cooling towers at the 960 MWE Rancho Seco Nuclear plant of the Sacramento Municipal Utility District evaporate around 13,000 acre feet of water per year, with a maximum evaporation rate in the hottest part of the season of about 12,000 gallons per minute.

In 1975, evaporation of this quantity of water by the Rancho Seco units did not represent a water loss of major importance. However, if one extends the use of cooling towers throughout the West and California, the potential competition for fresh water becomes an item worthy of prompt consideration and resolution.

A second concern about wet cooling towers is the possible alteration of local environments due to localized precipitation, fogging and/or icing. An instructive exercise involves calculating the net overall change in humidity, using the SMUD facility as an example.

Actual figures obtained from the weather bureau in Sacramento are: average annual temperature, 68°F; atmospheric pressure, 1,000 milobars; humidity, 30%; average annual wind velocity, 3 mph; cooling tower evaporation 12,000 gals./min.

At a relatively humidity of 30%, one cubic mile of air contains 6.36 x 10^6 gallons of water. Three cubic miles of air pass the towers in a 1-hour period, a volume of air which contains 18,900,000 gallons of moisture. Dividing that into 720,000 gallons per hour provides a net moisture increase of .038%, a quantity not likely to change the environment significantly.

Recall that the Carnot Equation is used to determine theoretical efficiency of heat engines. Efficiency (Et) is equal to the temperature of the heated liquid x 100 percent, measured in absolute units (°C + 273).

$$Et = \frac{T1 - T2}{T1} \times 100$$

Examining the equation, it's apparent that E will be equal to 0 if the T1 and T2 are equal.

A steam turbine with T1 of 900°F and T2, (condenser temperature) of 300°F, yields an efficiency of 66.6%. A point of extreme importance, and one that we will examine continually as we review the different types of energy transformation systems, is simply that the greater the difference between T1 and T2, the higher the efficiency of the unit.

It's essential that students master the principle of the Carnot Equation in determining unit efficiencies. As we enter the period of the need for increasing energy efficiency, and debate with increasing fervor the fate of thermal generating units, it's important to bear in mind the interrelationships of efficiency, fuel potentials and environmental impacts.

If the costs of producing electrical energy increase as predicted, due largely to higher costs of equipment and fuels, perhaps the aesthic objections of coastal plant siting will have to be balanced against greater efficiencies realizable through once-through cooling with seawater.

Let's consider next some of the atmospheric effects of thermal units which burn fossil fuels. An extremely complicating aspect of the combustion/pollution dilemma, traces to the fact that coal, petroleum and, to a much lesser extent, natural gas, demonstrate dazzling variations in chemical composition and in molecular structure. The ideal fossil fuel would be one which consisted of a pure hydrocarbon, i.e., only hydrogen and carbon.

Hydrogen and carbon properly combined with adequate quantities of oxygen would produce H_2O and CO_2, both relatively innocuous. Actually, fossil fuels contain a variety of impurities, with sulphur and ash the major unuseable villains. Even under ideal conditions, fossil fuels also yield oxides of nitrogen and sulphur as well as carbon monoxide.

Table 4-1, furnishes a detailed breakdown for carbon monoxide, particulates, sulphur oxides, hydrocarbons and nitrogen oxides produced by automobiles, power plants, industrial units, refuse burning and miscellaneous uses. Examination of those data demonstrates that automobiles produce 74% of all carbon monoxide. Automobiles also contribute some 53% of the hydrocarbons introduced into the atmosphere each year and 46% of the oxides of nitrogen. Power plants are responsible for about 73% of sulfur oxides, i.e., SO_2 and SO_3 and 42% of the oxides of nitrogen.

The table introduces facts which should make us "autophyles" all just a little uncomfortable. It indicates clearly that to point the finger of pollution blame at someone else for particulates, oxides of nitrogen, CO_2, SO_2, etc. is not a defensible response.

Fossil fuels, then, introduce undesirable materials into the environment. What can we do about it? As far as coal is concerned, the short-term impact on California's environment from coal use will be minor. The major part of the energy consumed in California is derived from petroleum and natural gas, both of which are relatively clean sources of energy. Unfortunately, both natural gas and petroleum are in short supply. Despite the environmental and energy advantages derived from their use, it's now plain that such advantages will not likely be available very far in the future.

That brings us back to coal. Circumstances suggest extended longterm use of this abundant fuel resource. A number of techniques already exist in the demonstration or experimental stages to reduce significantly the sulphur

Table 4-1

Estimated Emissions of Air Pollutants by Weight Nationwide, 1969;

Total 281.2 Millions Tons[a] (in millions of tons/year)

	Carbon Monoxide		Particulates		Sulfur Oxides		Hydrocarbons		Nitrogen Oxides		Total
Source	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount
Automobile	111.5	74	0.8	2	1.1	3	19.8	53	11.2	46	144.4
Power plants	1.8	1	7.2	21	24.4	73	.9	2	10.0	42	44.3
Industrial	12.0	8	14.4	41	7.5	22	5.5	15	.2	1	39.6
Refuse burning	7.9	5	1.4	4	.2	1	2.0	5	.4	2	11.9
Miscellaneous	18.2	12	11.4	32	.2	1	9.2	25	2.0	9	41.0
Total	151.4	-	35.2	-	33.4	-	37.4	-	23.8	-	281.2

[a] Council on Environmental Quality. Environmental Quality August 1971, US Govt P. Office

and ash found in coal. All these techniques, however, add substantially to the costs of coal-based energy, costs which ultimately must be picked up by the consumer.

Considerable media attention has been devoted to the fact that the low-sulphur deposits of coal in the western U.S. provide a workable alternative to liquid petroleum and natural gas. However, EPA regulations require that existing power generation units use coal containing not more than 0.7% sulphur by weight. New units, constructed after 1975, will be restricted to 0.6 pounds of sulphur per million BTU.

And in that term, "per million Btu," lies the trap. While it is true that the western coals contain smaller amounts of sulphur on a weight basis than some of the eastern anthracite and bituminous coals, the Btu release through chemical combustion is also lower. Western coal, then, may not be the panacea it is held out by some to be. Sulphur carried in coal in the form of pyrites can be removed physically, but the chemically bound sulphur cannot. And while chemical extraction processes are being developed, and do exist on an experimental basis, the processes are costly. Considerable doubt exists as to whether they represent feasible approaches toward mass production.

Any discussion of the thermal and environmental consequences of electrical generating units would be incomplete without mention of nuclear-fueled thermal units. As learned earlier, thermal efficiencies of nuclear units average about 32%, versus 40% for modern fossil-fueled units.

One of the frequently voiced charges against nuclear facilities is that they impose a much higher heat load on the environment than more efficient fossil-fueled facilities. That's true. The difference between 60% heat loss and 70% heat loss is substantial.

One of the aggravations associated with heat rejection by nuclear-fueled units is that essentially 100% of the rejected heat must be disposed of in the cooling water. In a fossil-fueled plant, at least a minor part is disposed of directly into the atmosphere through the exhaust of gases. On the plus side, however, a nuclear facility, emits no conventional pollutants such as oxides of nitrogen and sulphur, carbon monoxide or particulate.

Releases to the environment do exist, but they differ significantly. For example, routine operation of a pressurized water reactor, such as Rancho Seco, would routinely produce small quantities of xenon, krypton, iodine and tritium, all of which are either contained and shipped off-site for permanent storage or released following prescribed "delay and release" techniques.

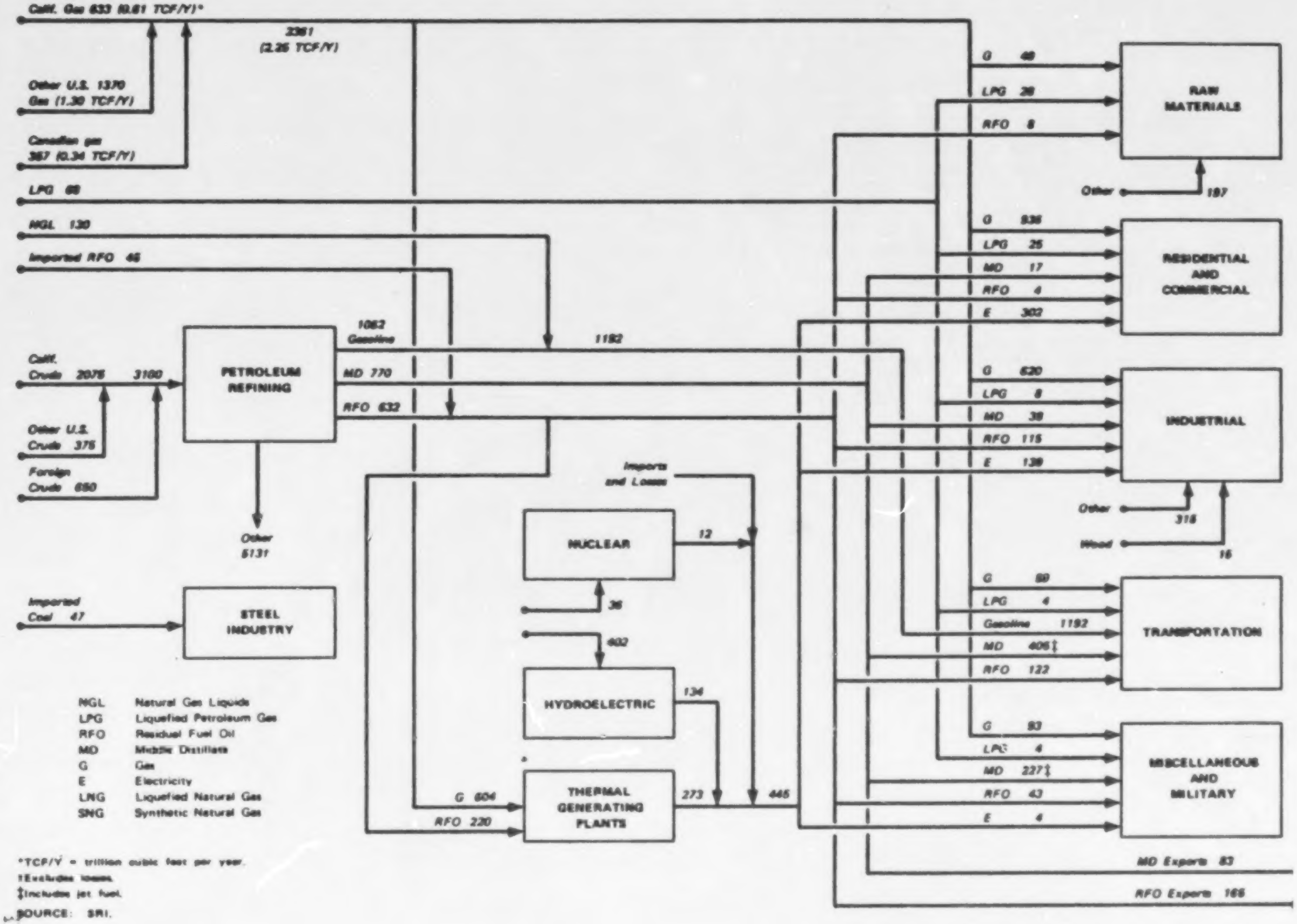
Around 20% of California's electricity comes from hydroelectric units located within the state. This is much more than the U.S. average of 4%. Hydroelectric power facilities tend to be placed in out-of-the-way locations and are, therefore, removed from the view of major portions of the population. But despite the fact that they exist in remote areas, some significant environmental effects do result and are worthy of mention.

- The development and operation of a hydroelectric plant invariably carries with it the loss of land which in many cases might be used in other worthwhile ways.
- There can be interruption of migration patterns of wildlife and indigenous aquatic species. Of particular concern is the interruption of spawning patterns of such anadromous species as salmon.

- Third, alteration of water temperatures by hydro facilities has at times had a deleterious effect on fish downstream from the dam. In some circumstances downstream flows have been interrupted drastically enough to threaten the ability of fish populations to survive.
- Fourth, particularly in such agricultural areas as the central section of California, alteration of water temperatures to produce colder-than-normal water has had adverse effects on the production of agricultural crops, such as rice.
- Finally, the development of dams and reservoirs interferes seriously with the transport of sand and gravel downstream. The reservoir itself is likely to fill in a predictable number of years, while simultaneously interfering with the regeneration of beaches and sand and gravel areas below the dams. (See Figure 4-1)

Figure 4-1

CALIFORNIA ENERGY BALANCE (TRILLIONS OF Btu), 1971


Calif. Gas 633 (0.61 TCF/Y)*
2361 (2.26 TCF/Y)
Other U.S. 1370 Gas (1.30 TCF/Y)
Canadian gas 367 (0.34 TCF/Y)
LPG 68
NGL 130
Imported RFO 46
Calif. Crude 2075
3100
Other U.S. Crude 375
Foreign Crude 650
PETROLEUM REFINING
1062 Gasoline
MD 770
RFO 632
1192
Other 5131
Imported Coal 47
STEEL INDUSTRY
Imports and Losses
NUCLEAR
12
36
402
HYDROELECTRIC
134
G 604
RFO 220
THERMAL GENERATING PLANTS
273
445
G 48
LPG 28
RFO 8
RAW MATERIALS
Other 197
G 936
LPG 25
MD 17
RFO 4
E 302
RESIDENTIAL AND COMMERCIAL
G 620
LPG 8
MD 38
RFO 115
E 139
INDUSTRIAL
Other 316
Wood 16
G 80
LPG 4
Gasoline 1192
MD 406‡
RFO 122
TRANSPORTATION
G 93
LPG 4
MD 227‡
RFO 43
E 4
MISCELLANEOUS AND MILITARY
MD Exports 83
RFO Exports 166

NGL	Natural Gas Liquids
LPG	Liquefied Petroleum Gas
RFO	Residual Fuel Oil
MD	Middle Distillate
G	Gas
E	Electricity
LNG	Liquefied Natural Gas
SNG	Synthetic Natural Gas

*TCF/Y = trillion cubic feet per year.

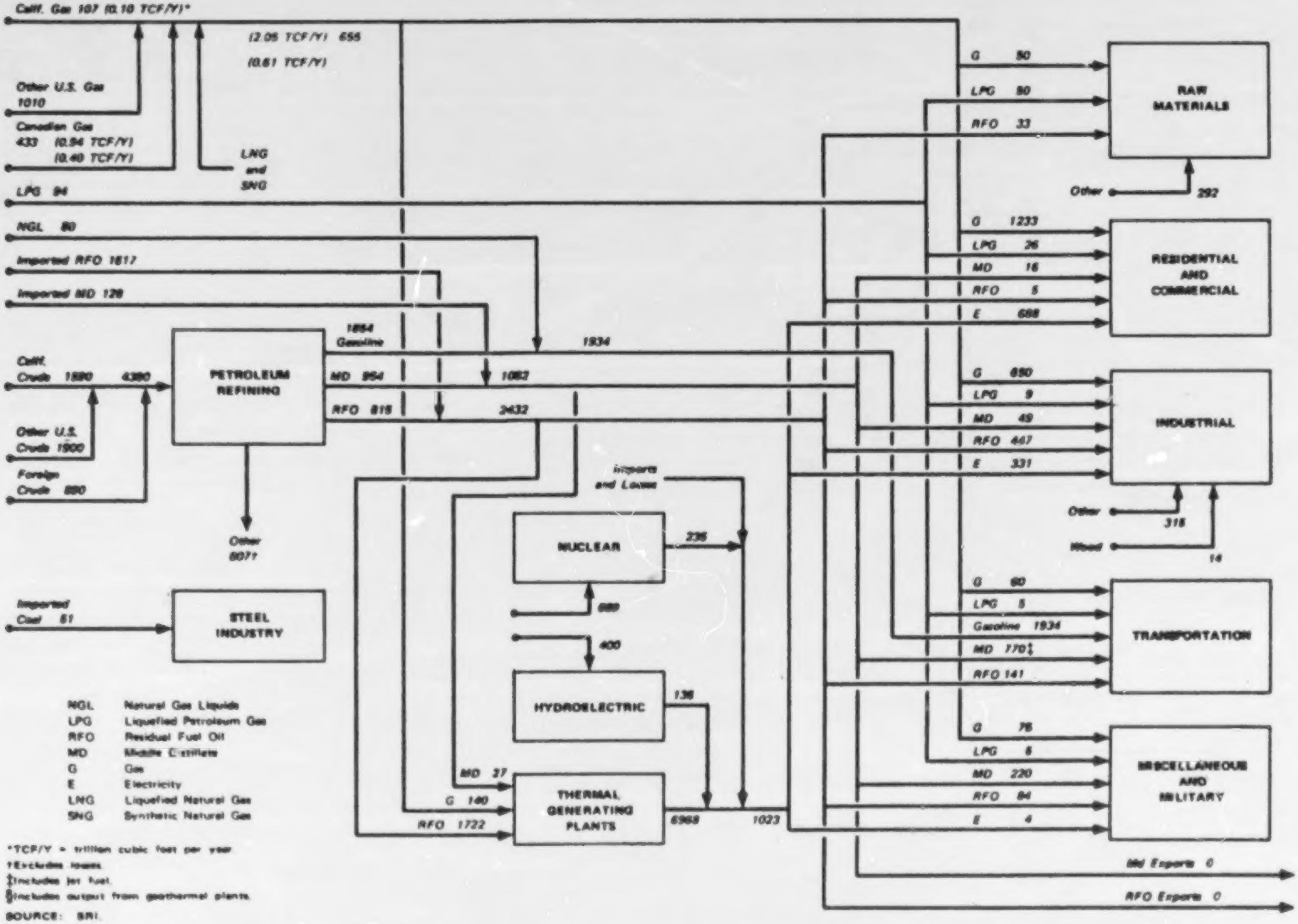
†Excludes losses.

‡Includes jet fuel.

SOURCE: SRI.

Figure 4-2

CALIFORNIA ENERGY BALANCE (TRILLIONS OF Btu), 1985


Calif. Gas 107 (0.10 TCF/Y)*
(2.05 TCF/Y) 655
(0.61 TCF/Y)
Other U.S. Gas 1010
Canadian Gas 433 (0.94 TCF/Y)
(0.40 TCF/Y)
LNG and SNG
LPG 94
NGL 80
Imported RFO 1617
Imported MD 128
Calif. Crude 1580
4380
Other U.S. Crude 1900
Foreign Crude 880
PETROLEUM REFINING
1854 Gasoline
MD 954
RFO 815
1934
1082
2432
Other 6071†
Imported Coal 51
STEEL INDUSTRY
Imports and Losses
NUCLEAR
236
689
400
HYDROELECTRIC
136
MD 27
G 140
RFO 1722
THERMAL GENERATING PLANTS
6968
1023
RAW MATERIALS
G 50
LPG 50
RFO 33
Other
292
RESIDENTIAL AND COMMERCIAL
G 1233
LPG 26
MD 16
RFO 5
E 688
INDUSTRIAL
G 850
LPG 9
MD 49
RFO 447
E 331
Other
316
Wood
14
TRANSPORTATION
G 60
LPG 5
Gasoline 1934
MD 770‡
RFO 141
MISCELLANEOUS AND MILITARY
G 76
LPG 6
MD 220
RFO 84
E 4
Md Exports 0
RFO Exports 0

NGL	Natural Gas Liquids
LPG	Liquefied Petroleum Gas
RFO	Residual Fuel Oil
MD	Middle Distillate
G	Gas
E	Electricity
LNG	Liquefied Natural Gas
SNG	Synthetic Natural Gas

*TCF/Y = trillion cubic feet per year.

†Excludes losses.

‡Includes jet fuel.

§Includes output from geothermal plants.

SOURCE: SRI.

CHAPTER 5

BIOLOGIC EFFECTS OF ENERGY SYSTEMS

Any discussion of the biologic effects of energy conversion systems requires an understanding of the setting in which energy utilization occurs.

The planet Earth is a solid liquid sphere of approximately 4,000 miles radius, surrounded by an ocean of air approximately ten miles in depth. Man's activities are affected greatly by the atmospheric environment and, conversely, it's becoming increasingly apparent that man's activities can affect the environment itself.

This emerging awareness is of significance because, until recent years, it was widely held that the air envelop surrounding the planet earth was so massive that little alteration might ensue, regardless of man's activities. Much the same reasoning has been applied to the oceans of the planet; but, in the last few decades, that long-held concept has also undergone considerable transformation. The atmosphere's chemical and physical properties exert considerable regulation on the energy reaching the land and water surfaces of the earth. Additionally, the energy flow actually reaching the earth's surfaces experiences considerable movement between the equators and the poles.

This means that material entering the Northern Hemisphere tends, even over many decades, to remain in the hemisphere of origination. It's erroneous to assume, therefore, that environmental degradation which might occur in the Northern Hemisphere, for example, will be shared by those south of the equator.

By volume, 99% of our air consists of nitrogen and oxygen, their percentages being about 78 and 21, respectively. Smaller amounts of rare gases, water vapor, carbon dioxide and particulates constitute the remaining one percent. (Figure 5-1) Seventy-two percent of the outer surfaces of the solid portion of the earth is covered by water. Interestingly, about 97% of all the planet's water is contained in the salty oceans. Of the 3% remaining, less than 10% or .3%, is fresh water available for man's use.

Some scientists are concerned that increases in the percentage of carbon dioxide in the atmosphere can have the effect of reducing the rate of surface cooling of the earth and, ultimately, of increasing ambient temperatures to the point where the polar ice caps could melt. The point to keep in mind is that some scientists hold that the earth's energy balance must operate within a range of about 2° Centigrade downward from existing temperature regimes. More cooling, it is felt, could produce another ice age; or an increase in temperature, and the ushering in of an ice-free age. Offsetting the effects of increasing percentages of carbon dioxide in the atmosphere is the influence of particulate matter introduced into the environment by man's activities and occasional volcanic erruptions and desert storms. Much remains to be learned of the factors involved in maintaining a global heat balance. Certainly it appears that we should keep in mind the ultimate effects of introducing chemicals or materials which could adversely affect the present climatic regimes.

Let's now examine some of the environmental effects introduced by the combustion of fossil fuels and nuclear fission.

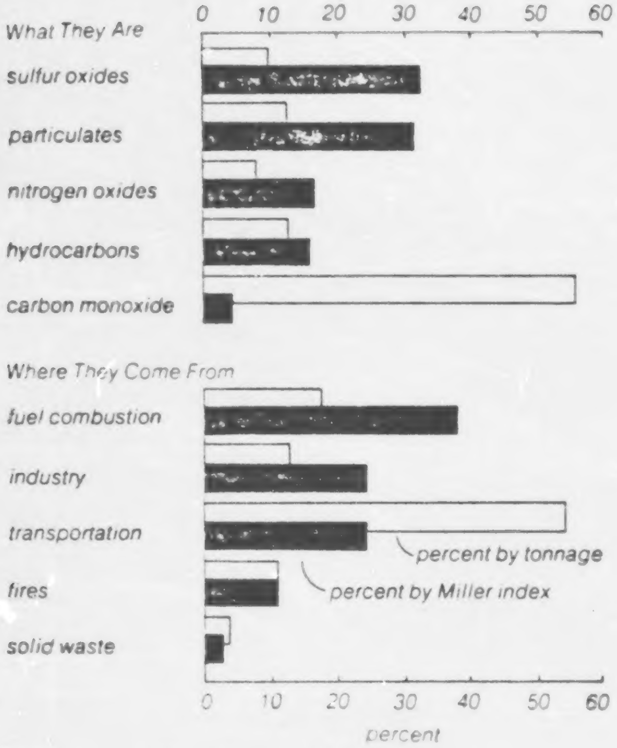
Five classes of pollutants have been identified: oxides of sulphur, oxides of nitrogen, hydrocarbons, carbon dioxide and particulate. (Table 5-1) Since pollution is certainly a legitimate concern, let's look at how each of these materials occurs and how they affect plants and animals.

Each of us requires approximately 30 pounds of air per day, which can be converted to 2,000 gallons every 24 hours or about 1.3 gallons per minute.

Fossil fuels are responsible for between 85% and 90% of all pollutants introduced into the atmosphere. It's important to note, however, that not all materials introduced are the consequences of combustion. For example, considerable quantities of carbon monoxide and carbon dioxide are formed naturally through the oxidation of methane, a natural product of bacterial decomposition of soil and water. Oxides of sulphur are emitted in significant quantities from volcanoes and also occur in most areas where residual volcanic or geothermal activity exist. Finally, oxides of nitrogen are produced in considerable quantities by soil bacteria. In all cases noted above, however, naturally occuring pollutants exist in lower levels and are dispersed over far larger geographic areas.

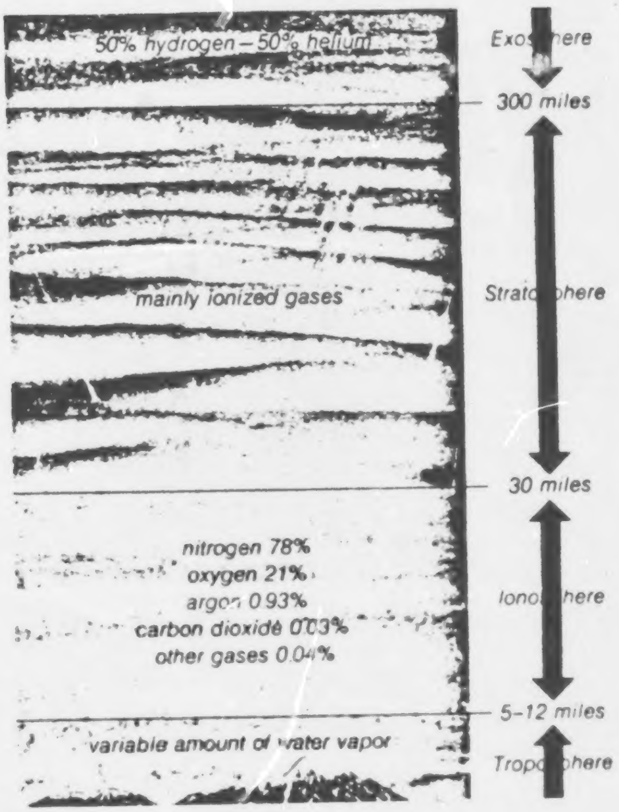
Any discussion concerning major air pollutants must include definition of what a pollutant is and make clear the distinction between primary and secondary pollutants. A common definition of a pollutant is a material introduced into the environment, air, water or soil -- in sufficient concentration to produce harmful or deleterious effects on man or animals or other forms of life. (Table 5-2) The two major types of pollutants are (a) primary pollutants, or those added directly to the air. Included in this classification could be particulates, carbon dioxide, oxides of sulphur and oxides of nitrogen, (b) secondary pollutant, or materials formed as a result of primary pollutants in consort with oxygen, ultraviolet radiation, temperature or moisture. A number of effects can be, and generally are, involved in bringing about the chemical reactions responsible for formation of the secondary pollutant known as photochemical smog.

Table 5-1



Air pollutants and their sources for the United States in 1970. Two percentages are shown. One is based on tonnage of emissions (Council on Environmental Quality 1972), and the other is based on a weighted index that takes into account the relative health effects of each pollutant.

Figure 5-1


50% hydrogen – 50% helium
Exosphere
300 miles
mainly ionized gases
Stratosphere
30 miles
nitrogen 78%
oxygen 21%
argon 0.93%
carbon dioxide 0.03%
other gases 0.04%
Ionosphere
5–12 miles
variable amount of water vapor
Troposphere

The composition and structure of our finite air supply.

Table 5-2

Harmful effects of some major air pollutants

Pollutant	Human health	Animal health	Plant life	Deterioration of materials	Soiling	Esthetic
Particulates	☐	☐	☐	☐	☐	☐
Sulfur oxides	☐	☐	☐	☐	☐	☐
Oxidants (ozone, PAN, etc.)	☐	☐	☐	☐		☐
Carbon monoxide	☐	☐				
Hydrocarbons	☐	☐				☐
Nitrogen oxides	☐	☐	☐	☐		☐
Noise	☐	☐				☐
Fluorides	☐	☐				☐
Asbestos	☐	☐		☐		☐
Lead	☐	☐				☐
Beryllium	☐	☐				☐
Arsenic	☐	☐				☐
Cadmium	☐	☐				
Nickel	☐	☐				
Mercury	☐	☐	☐			

Source: Environmental Protection Agency

In terms of tonnage, oxides of carbon constitutes the major portion of pollutants introduced into the environment. Most of the carbon dioxide (CO_2) found in the atmosphere is initially introduced in the form of carbon monoxide (CO) which is a colorless, odorless gas. A major part of the carbon monoxide occurring in the atmosphere is derived from natural sources associated with the decay of cellulose materials in soil or water. Once introduced into the environment, the carbon monoxide is converted by soil organisms and chemicals within the atmosphere into the less harmful CO_2.

The relatively small percentage of oxides of carbon introduced by man comes primarily from the combustion of fossil fuels. The internal combustion engine is the primary contributor. Best estimates suggest that nearly 80% of the carbon monoxide and carbon dioxide introduced by man result from incomplete combustion of hydrocarbons in vehicles. The carbon monoxide which result in this fashion is harmful to humans and animals, because CO has a capability for reacting with hemoglobin in the blood and, under conditions of prolonged exposure at elevated concentrations, can result in deprivation of oxygen to cells within the body. Headaches, fatigue and nausea are some of the common symptoms under extreme conditions.

Hydrocarbons, containing, as the name suggests, hydrogen, carbon and oxygen, constitute the second largest group of pollutants on a weight basis. Particularly troublesome in urban and industrial areas, hydrocarbons result primarily from incompletely burned fuels. It is estimated that nearly 40% of all hydrocarbons originate from the internal combustion engine and from the release of industrial solvents during manufacturing and refining processes.

Health effects of hydrocarbons are not completely understood, but some, particularly the benzopyrene group, appear to be carcinogenic. Hydrocarbons play a minor role in the development of photochemical smog common to such areas as the Los Angeles basin and Mexico City.

Particulates constitute the third largest pollutant group in terms of quantities introduced; they are solid or liquid particles carried in the air. Examples of man-made particulates would include smoke, soot, dust, oil and asbestos fibers. Natural particulates such as dust and pollen, volcanic ash and salt nucelli add to the total particulate load. Particulates have at least two adverse effects.

Eye irritation typically results from reflection of light by particulates carried in heavy concentrations in the atmosphere. The effect of these heavy particulate loads is a magnification of the light reaching the eyes and a consequent burning eye irritation and reddening of the eye membranes.

The second adverse particulate consequences is its effect on the respiratory system. Under circumstances of normal exposure to solid and liquid particulates, small cellular extensions within the respiratory tract can carry away the major particulate load ingested, either by digestion or elimination from the body entirely. It is in cases of lung damage or respiratory disease where particulates create the greatest health concern. The technology for the control of the major particulate pollutants either exists today or is approaching the stages of development where airborne particulate matter should no longer constitute a problem.

Oxides of sulphur (SO_2, SO_3) originate largely through the combustion of fossil fuels, primarily coal and petroleum, which contain significant quantities of sulphur-bearing compounds. In high concentrations, oxides of sulphur are acrid, corrosive and poisonous. Since sulphur was a primary ingredient of ancient plants which formed today's fossil fuels, it follows that sulphur exists in significant quantities in our coal and petroleum. SO_2, the sulphur dioxide formed from combustion, reacts with the free oxygen in the air to form SO_3. SO_3, in turn, combines with the water in the air to form H_2SO_4, a corrosive and damaging material.

At least two avenues exist for reducing oxides of sulphur emitted to the environment. One, the procedure being utilized to the greatest extent at the present time, is the utilization of petroleum containing very low percentages of sulphur. The second procedure is the removal of the sulphur, either before or after combustion. Techniques for this add considerably to the economic burden associated with power generation.

Oxides of nitrogen, i.e., nitric oxide and nitrogen dioxide, possess a pungent choking odor and are produced through the action of the combining of nitrogen and oxygen in the air at the high temperatures produced in boilers, turbines and internal combustion engines. Procedures already exist to limit the production of NO_x, and while industry has succeeded in limiting oxides of nitrogen by restricting combustion temperatures to not more than 2900°F, such control has been achieved at the cost of reduced efficiency in the combustion units. Nitrogen dioxide is classified as a lung irritant and is believed responsible for some damage to plants. Its greatest aggravation is its role in the formation of photochemical smog.

In considering ways to minimize the introduction of pollutants, control measures should not be based solely on tonnages emitted. It is apparent that significant differences exist in the effect of various pollutants on animal and plant tissues. The development of control measures based on the relative toxicity of the pollutants and the period of time each remains active in the environment would seem a logical approach. If such an index were used, one could examine the role of carbon monoxide in the environment. Although ranked first in order of its total tonnage, CO is last in its effect on plant and animal life.

Although smaller in tonnages, oxides of sulphur and nitrogen certainly assume a larger role than CO.

Regardless of the air quality and evaluative procedures ultimately developed, it is important to stress the need for evaluative devices which consider not only the immediate and obvious effects of pollutants, but also the long term consequences of materials foreign to the environment. Unless such a system is developed, it's quite likely that wasted effort and considerable sums of money will be expended in a will-of-the-wisp investigation of pollutants of minor significance.

A case in point is lead in the atmosphere, the major source of which comes from leaded gasoline burned in automobiles. Present figures suggest that there is one car for every other person residing in the U.S. With each vehicle contributing something between 3 and 4 pounds of lead per year, each of us has the opportunity to inhale particles of lead compounds, the biological consequences of which are really little understood. The suggestion here is that as programs are developed to reduce or establish maximum levels for pollutants believed to be of primary significance, our energies must be directed toward those materials of demonstrable significance. Our limited resources must not be squandered in pursuit of pollutants of questionable importance. (Figure 5-2 & 5-3)

It's been theorized that a doubling or possibly even a tripling of the percentage of carbon dioxide in the environment could occur by the year 2050. Should this happen, the ambient temperature could increase by as much as 2°C. (3.6°F). If this in turn were to trigger a melting of the Antarctic ice, a process which would occur over some hundreds of years, the level of the oceans would rise from two to three hundred feet, flooding some 20% of the present land area of the world.

RADIATION - NATURAL AND MAN-MADE

Most scientists believe that man has always been exposed to a background of natural radiation from cosmic sources and naturally-radioactive materials contained in the environment and the earth's crust. Estimates of the naturally occurring background radiation vary from 100 to 200 millirems* annually. But the decision has been made by the U.S. Environmental Protection Agency (EPA) to use 130 millirems as the average annual background exposure for U.S. citizens. EPA has also decreed that the U.S. maximum allowed radiation exposure from man-made sources shall be 170 millirems a year.

A major portion of the natural radiation to which man is exposed has its origin in cosmic radiation from outer space. These cosmic particles, which are extremely energetic (billions of electron-volts), are attenuated in

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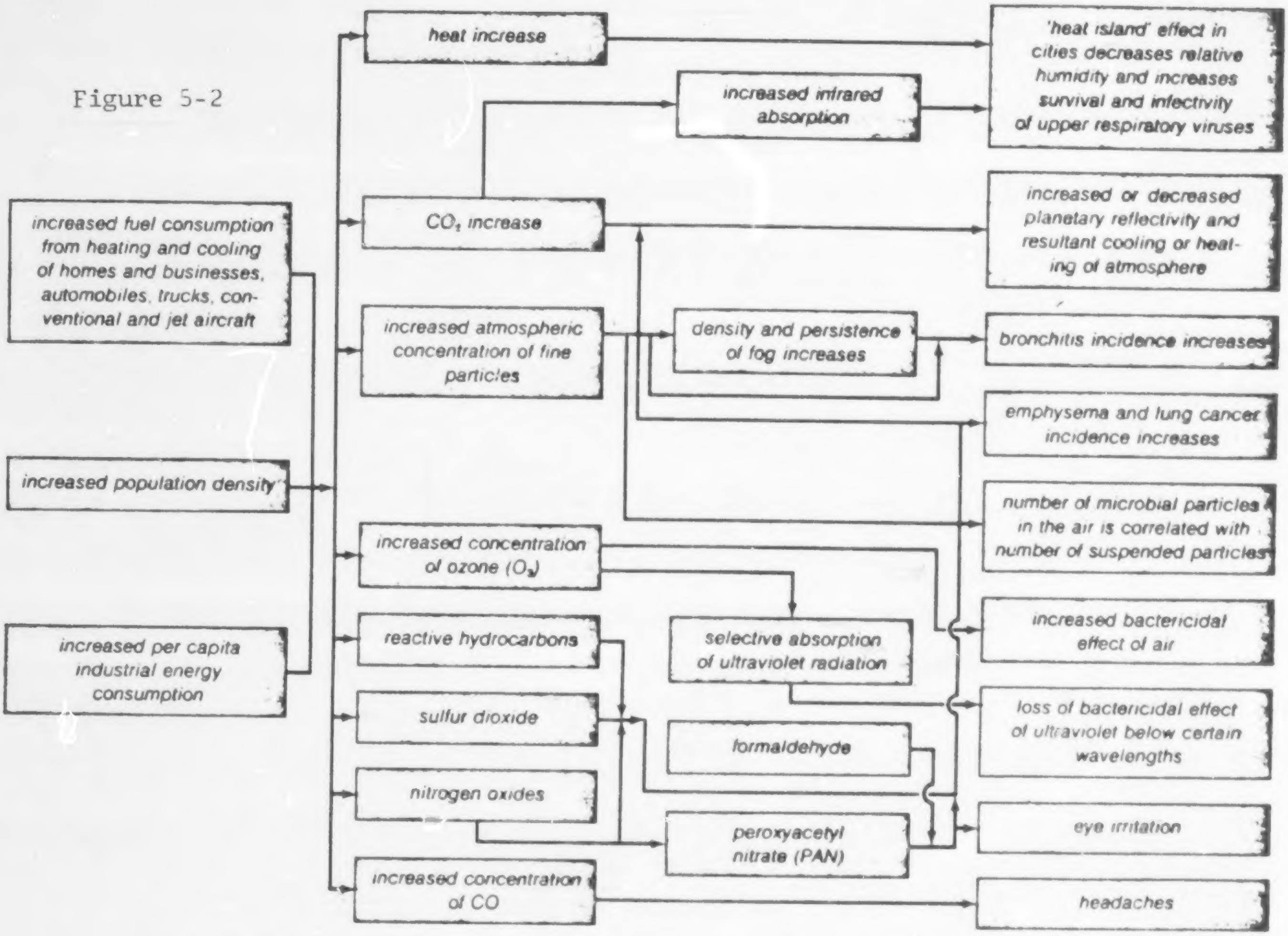
* See Appendix for analysis of background radiation.

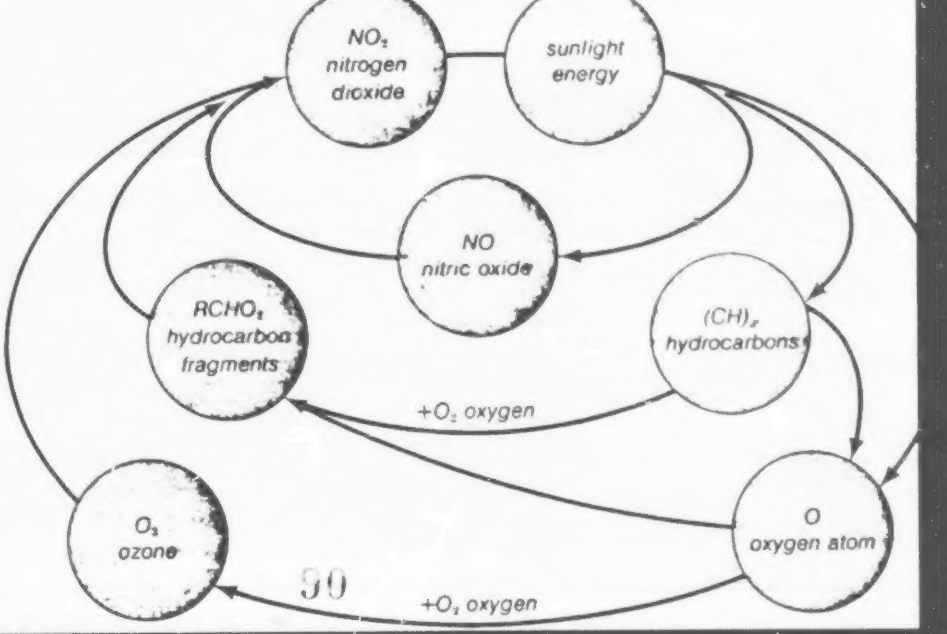
Figure 5-2


heat increase
'heat island' effect in cities decreases relative humidity and increases survival and infectivity of upper respiratory viruses
increased infrared absorption
increased fuel consumption from heating and cooling of homes and businesses, automobiles, trucks, conventional and jet aircraft
CO_2 increase
increased or decreased planetary reflectivity and resultant cooling or heating of atmosphere
increased atmospheric concentration of fine particles
density and persistence of fog increases
bronchitis incidence increases
emphysema and lung cancer incidence increases
increased population density
number of microbial particles in the air is correlated with number of suspended particles
increased concentration of ozone (O_3)
increased bactericidal effect of air
increased per capita industrial energy consumption
reactive hydrocarbons
selective absorption of ultraviolet radiation
sulfur dioxide
loss of bactericidal effect of ultraviolet below certain wavelengths
formaldehyde
nitrogen oxides
peroxyacetyl nitrate (PAN)
eye irritation
increased concentration of CO
headaches

A crude model of air pollution and some human ecological effects. (Modified after Institute of Ecology 1969)

Figure 5-3

A crude model of the formation of photochemical smog. Through a complex reaction sequence (not shown here) the primary pollutants, NO, NO_2, and hydrocarbons $(CH)_x$, react with sunlight to produce the secondary pollutants ozone (O_3) and various hydrocarbon compounds ($RCHO_2$). (Modified from U.S. Department of Health, Education, and Welfare 1970d, p. 3)


NO_2 nitrogen dioxide
sunlight energy
NO nitric oxide
$RCHO_2$ hydrocarbon fragments
$(CH)_x$ hydrocarbons
$+O_2$ oxygen
O oxygen atom
O_3 ozone
$+O_2$ oxygen

their biologic effects primarily through their interaction with components of the earth's atmosphere. As one might expect, altitude has an influence on radiation exposure. Persons living at such higher elevations as Denver or the mountainous sections of Chile and Peru have higher exposure rates than persons living at or near sea-level. Radiation dose also is affected by the earth's magnetic field. Since the earth is surrounded by magnetic lines of forces stretching from pole to pole, the greatest deflection of the charged cosmic particles occurs at the equator. If one were interested in minimizing exposure to cosmic radiation, the ideal homesite would be on land a few feet above sea level at the equator.

The balance, and smaller portion, of background radiation has its origin in radioactive decay associated with long-lived radionuclides such as potassium 40, radon 222, carbon 14, uranium 235, and of tritium, which are common throughout the world. The water we drink, the air we breath, and much of the food we eat contain extremely minute quantities of naturally occurring radionuclides.

Man-made radiation has many sources including decay by-products of nuclear weapons systems, color television, radioisotopes associated with nuclear electric generating units, medical x-rays and radiotherapy. A primary and important difference between natural and man-made radiation is that the latter is in much more concentrated form and thus can be dangerous if adequate exposure safeguards are not observed.

Let's now consider the three primary forms of radiation and the reactions of living materials to ionizing radiation. The alpha particle, symbolized by the Greek letter A, is for all practical intents and purposes, the physical equivalent of the nucleus of the helium atom associated with the "heavy" elements, alpha particles are massive, doubly charged (++), have low penetrating power and can easily be stopped by a piece of paper or the epidermis of the body.

The major concern with alpha radiation is where alpha-emitting substances may be ingested or inhaled into the lungs. Under certain circumstances where alpha materials are inside the body, the ionization potential of the alpha particle is great and extensive localized radiation damage can result.

Beta particles are electrons and, depending on their charge, may be classified as positrons or negatrons. One consequence of their decreased size and mass is greater penetration capability. Although greater penetration can result, the decrease in mass causes a decrease in ionization potential and, on a one-for-one basis, the beta particle is much less effective in an ionization sense than an alpha particle.

Gamma rays are essentially x-rays, i.e., they are nonparticulate and possess no charge, plus or minus. Hence, gamma rays are not influenced by magnetic fields and their nonparticulate nature gives them great penetration capability. Several inches of lead or several feet of concrete may be required to shield material from high-energy gamma radiation. The following table depicts common isotopes, their half-lives, and types of radiation.

Isotopes	Half-Life in Years	Types of Radiation
Radium 226	1,622	Alpha and Gamma
Uranium 238	4.5×10^9	Alpha
Thorium 232	1.4×10^{10}	Alpha and Gamma
Potassium 40	1.4×10^9	Beta and Gamma
Tritium	12.3	Beta
Carbon 14	5,730	Beta

In his article, "Ionizing Radiation Standards for Population Exposure," J. A. Lieberman indicates that the average person in the U.S. receives an annual exposure of 50 millirems from cosmic radiation from the earth and building materials. An additional 25 millirems is received internally from inhalation of air (5 millirems) and from isotopes formed naturally in human tissue (20 millirems). Diagnostic X-rays and radiotherapy contribute some 60 millirems more, and the nuclear industry, television, radioactive fallout and other sources account for about 5 millirems a year. Thus, Lieberman calculates an average exposure of approximately 190 millirems a year.

A number of terms are used to designate radiation characteristics, and it is essential that a clear understanding of the differences associated with each of the terms be developed.

The first generally accepted unit of radiation intensity we shall consider is the roentgen (R). The roentgen is a useful measure for radiation in general, but is of little value in calculating the biological effects of radiation. In 1928, the Second International Congress of Radiology adopted the roentgen as the official unit. The roentgen is now defined as "the quantity of X or gamma radiation such that the associated corpuscular emmision per .001293 gram of air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either side." The deficiencies of the roentgen as a unit of radiation are its restriction to X or gamma rays and the requirement that roentgen measurements must be carried out under specific and carefully controlled conditions.

The specific nature of the roentgen culminated in the development of a new unit, the rad, in 1956. The term, rad, meaning radiation absorbed dose, corresponds to 100 ergs of radioactive energy absorbed in one gram of tissue. Thus the rad is less restrictive than the roentgen and is a measure of the energy absorbed in a specific volume of matter. When the subject is tissue, the roentgen and rad are essentially the same and often are used interchangeably. Despite the extended measurement capability of the rad over the roentgen, however, the rad still does not take into account the relative intensity of biological damage of different forms of radiation in different types of tissue. Consequently, a third term, the rem (roentgen equivalent man or mammal) was developed.

In contrast to the rad which is defined as 100 ergs per gram of absorbed energy in any medium from any type of ionizing radiation, the rem accounts for the biological damage produced. This measurement considers factors such as differences in tissue, i.e., muscle or bone, energy levels and general characteristics of the radiation source. The rem represents the basic unit used in the measurement of radiation effects and is the one with which students should be familiar. A millirem is, of course, 0.001 rem.

RADIATION EFFECTS

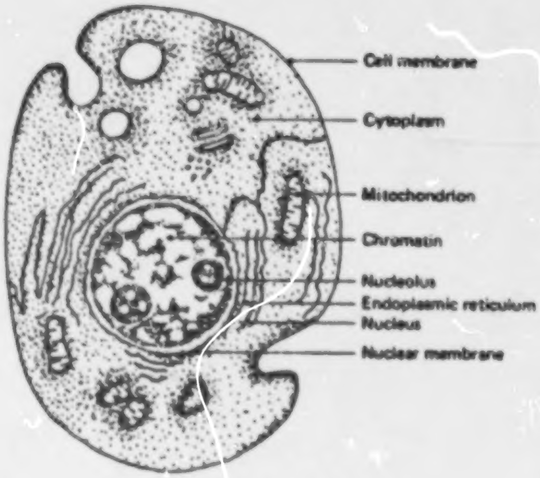
Exposure to radiation affects living tissues in two primary fashions. The first, classified as genetic damage, involves reproductive cells and includes the danger of producing mutations which may be passed on to future generations. The second is somatic damage which involves destruction of tissues other than reproductive cells. The consequences of somatic damage is confined to the individual in which the damage occurs but can be responsible for abnormal fetuses, cancer in various parts of the body, leukemia, cataracts and other diseases having the effect of shortening a normal life span.

Ionization is a random process with a relatively small percentage of the body tissues susceptible to damage. At least two mechanisms appear to be involved. One is alteration through direct action, such as a charged particle striking a part of the chromosome or a particular locality which will create somatic damage. Secondly, there is indirect action where some of the free radicals created through ionizing radiation react with organic molecules within the cell to create cell or tissue changes. Since cells operate on a finely balanced basis, any change upsets the status quo, and potential harm is a possible consequence. (Figure 5-4)

In cases where chromosome "breakage" occurs, the chromosome threads are broken either by the passage of an ionizing particle or by an attack upon them of one of the free radicals created through indirect hits. The severed ends of the chromosomes possess the capability for rejoining but they seem to be essentially indiscriminate in this process. If the severed ends of the same particle happens to come together, restitution occurs. However, if two different chromosomes are joined and a permanent loss of the original genetic characteristic results, an error in the transmission of the genetic code traditional within the organism results.

Major disagreement exists among many experts concerning the level or exposure at which damage from ionizing radiation is initiated. There appears to be general agreement that any exposure to ionizing radiation, whether

Figure 5-4


Cell membrane
Cytoplasm
Mitochondrion
Chromatin
Nucleolus
Endoplasmic reticulum
Nucleus
Nuclear membrane

Schematic depiction of a cell showing its main components.

natural or background, harbors the capability for genetic alteration. However, there is major disagreement over whether exposure to low levels of radiation cause somatic damage such as cancer or leukemia. Some scientists hold that all radiation is harmful regardless of the level or intensity. Others hold that low-level doses of radiation tend to be tolerated by organisms and may not necessarily be harmful. (Table 5-3, 5-4)

Proponents of the first position, known as linear response, suggest that any increase in radiation is intolerable and that a direct relationship exists between increased exposure and radiation-related illnesses.

Proponents of position two, identified as the threshold level of tolerance, hold that man has developed through the ions under constant exposure to low-level radiation and that as an organism, he is able to tolerate low levels of exposure. One conclusion of that position is that until radiation exposure level exceeds significantly the background levels of radiation, no increase in cancer or radiation-related illnesses can be expected.

Since the adherents to each of the two positions have developed impressive quantities of data supportive of their respective hypotheses, it is unlikely that this impasse will soon be broken.

Table 5-3

The Relative Biological Effectiveness (RBE) of different types of radiation*

Radiation	RBE
X, gamma and beta rays (above 50 KeV)	1
Electrons	1
Thermal neutrons	2.5
Fast neutrons	10
Alpha particles	10
Protons	10
Heavy ions or nuclei	20

*Adapted from data provided by the International Commission on Radiological Protection (ICRP)

Table 5-4

X-ray and gamma ray doses required to produce various somatic effects

Dose (rads)	Effect
0.3 weekly	Probably no observable effect
60 (whole body)	Reduction of lymphocytes (white blood cells formed in lymphoid tissues as in the lymph nodes, spleen, thymus, and tonsils)
100 (whole body)	Nausea, vomiting, fatigue
200 (whole body)	Reduction of all blood elements
400 (whole body)	50% of an exposed group will probably die
500 (gonads)	Sterilization
1000 (skin)	Erythema (reddening of the skin)

CHAPTER 6

HYDROELECTRICITY

Hydroelectric facilities, while in themselves quite complicated, are relatively simple in comparison to most other energy transformation systems. Despite the modest contribution of hydroelectric units to the total U.S. energy scene, hydro units hold a special appeal, perhaps because of their historical significance in the U.S. and in California. It appears that the first commercial hydroelectric plant in the U.S. was built in 1882 in Wisconsin. Hydro power moved to the Pacific Coast in 1886 when the Spokane (Washington) Falls Water Power Co. lighted the village with 10 arc lamps powered by a generator rescued from a defunct coastal steamer.

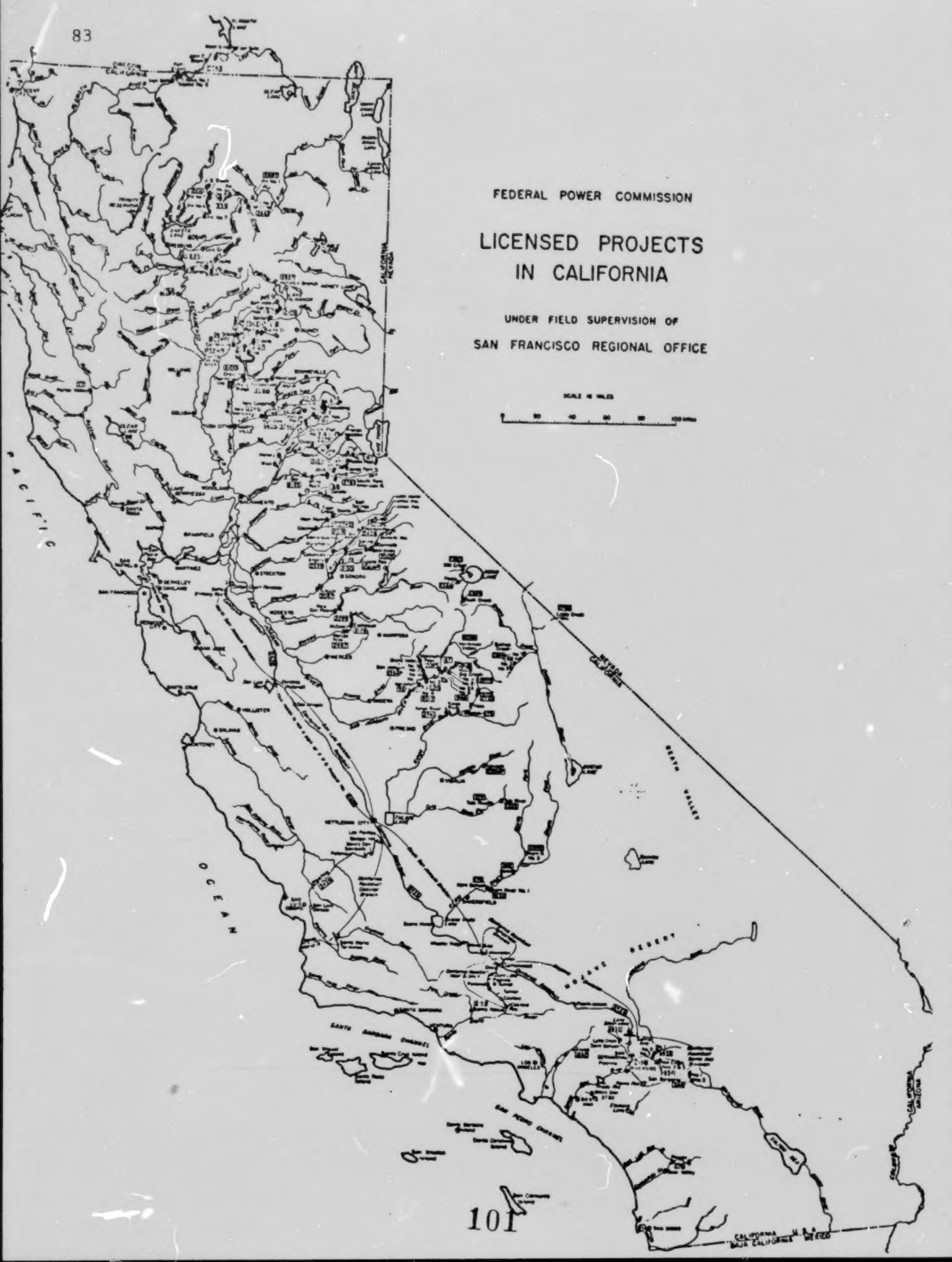
The site of the first hydroelectric plant in California has not been completely established, but evidence suggest that a small direct-current generator was installed near Colton in Southern California in 1887. It supplied electricity to the City of San Bernardino, eight miles distant. From that modest beginning, hydro power in California grew into a system which incorporated 171 units in 1974. (See Federal Power Commission Map)

The production of hydroelectric energy in the U.S. has doubled in the last 25 years. But, despite that doubling, the contribution of hydroelectric energy to the total U.S. energy basket has remained essentially constant at about 4% of total U.S. energy needs. Irregardless of our possible interest in increasing the hydroelectric contribution to U.S. energy needs, 4% represents, for all practical purposes, a functional limit.

From the standpoint of contributions to the total energy scene, California is atypical in its hydroelectric resources. In 1974, a particularly wet year, about 30% of California's electrical energy came from hydro sources. Two-thirds of that, or about 20% of the total electrical energy consumed in-state, was produced at California facilities. The remaining 10% was imported from the Pacific Northwest.

As noted earlier, California presently has more than 170 hydroelectric units; their combined installed capacity is about 32,000 megawatts. About one-half of the hydroelectric energy produced in the U.S. is produced in Washington, Oregon and California, with the contributions at 25%, 12% and 12% respectively. For the Pacific Gas and Electric Company, 25% to 26% of 1974 installed capacity is represented by hydro facilities. Interestingly, for the period 1973-74 and 1974-75, almost 50% of PG&E's electrical energy send-out was from hydro. The difference lies in purchases from other producers in Northern California and out of State and in unusually good snowfall and rainfall across Northern California and Pacific Northwest mountain watersheds. (See Figure 6-1)

We now turn our attention to two systems, conventional and pumped storage, whereby hydro power is generated. Depending upon the "head," or height of the water above the turbines, and the volume of water available, turbines may be of three types. The first, called the Francis (reaction) type, is normally used in a variety of head or pressure situations, varying from 40 ft. to 1,000+ ft. In contrast, the Pelton (impulse) type unit is designed to operate at head pressures in excess of 850 ft. The Kaplan type is used for heads less than 100 feet. (See Figure 6-2)



FEDERAL POWER COMMISSION

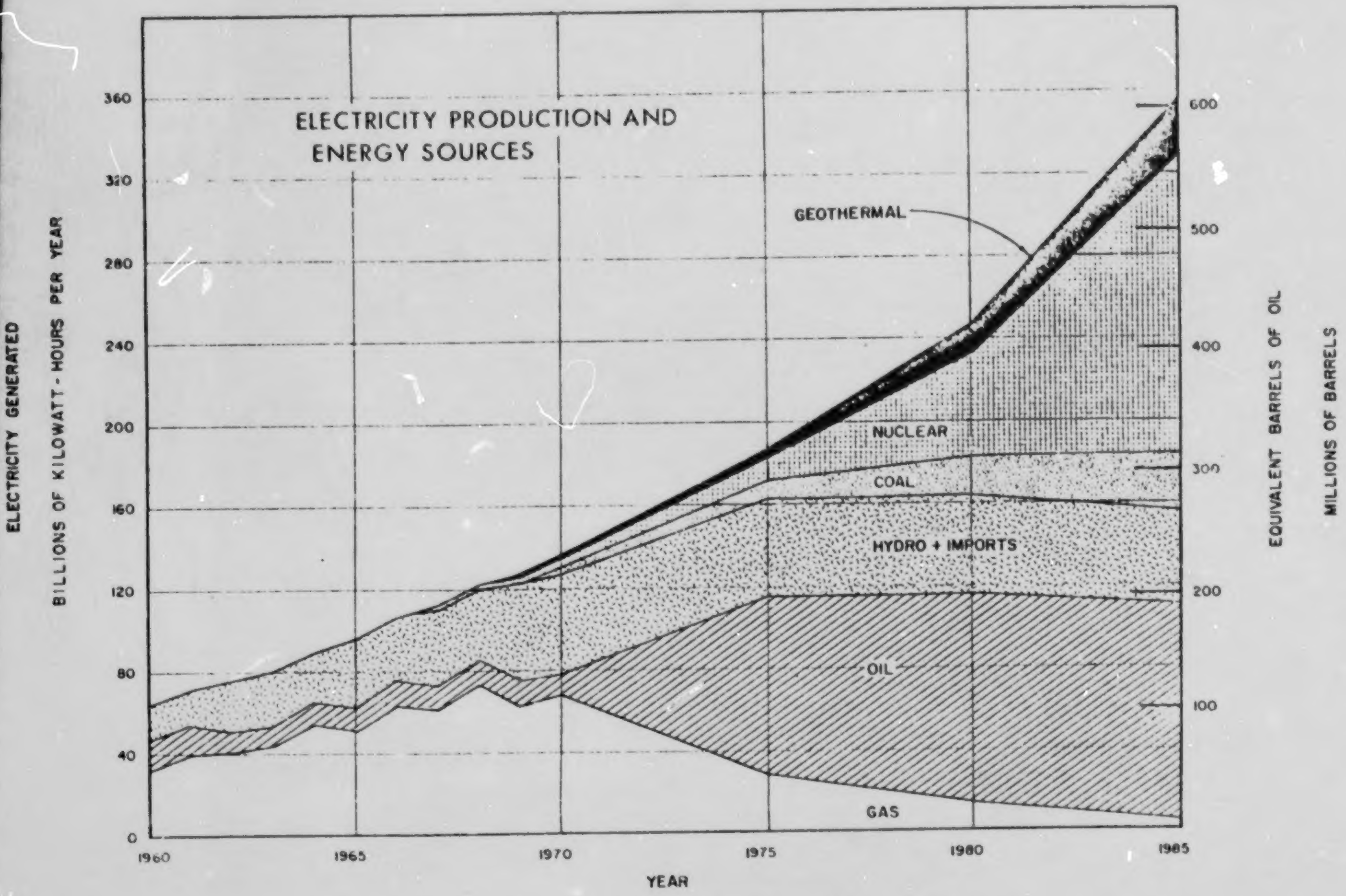
LICENSED PROJECTS IN CALIFORNIA

UNDER FIELD SUPERVISION OF

SAN FRANCISCO REGIONAL OFFICE

OREGON
CALIFORNIA
CALIFORNIA
NEVADA
NEVADA
CALIFORNIA
PACIFIC
OCEAN
DEATH VALLEY
MOJAVE DESERT
SAN FRANCISCO
OAKLAND
BERKELEY
STOCKTON
MODESTO
FRESNO
VISALIA
BAKERSFIELD
SANTA BARBARA CHANNEL
SAN PEDRO CHANNEL
CALIFORNIA
ARIZONA
CALIFORNIA U.S.A.
BAJA CALIFORNIA MEXICO

Figure 6-1



Source: "Energy Dilemma." California Resources Agency, June 1973

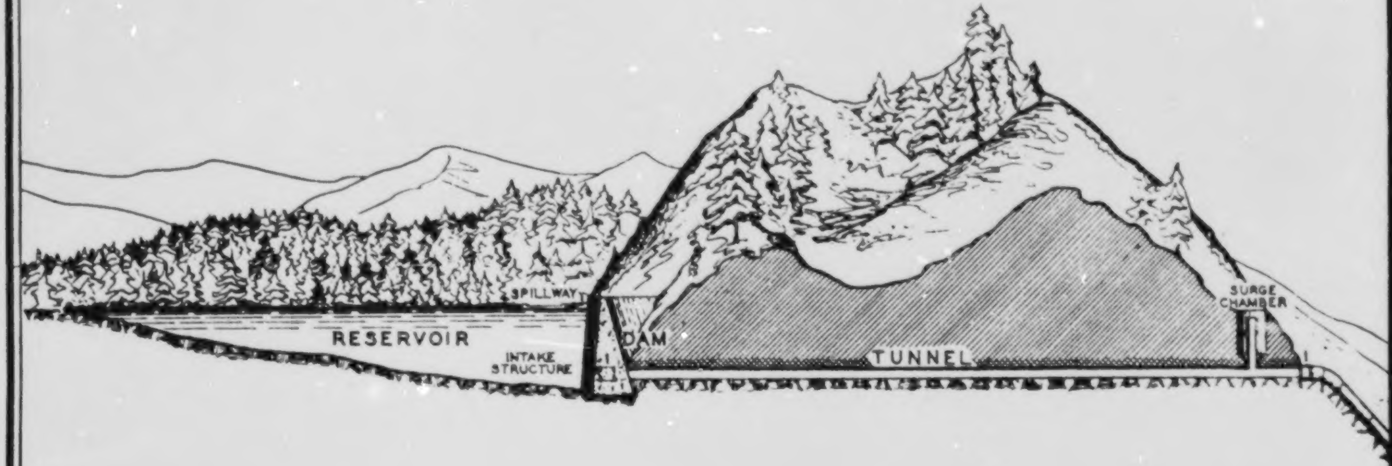
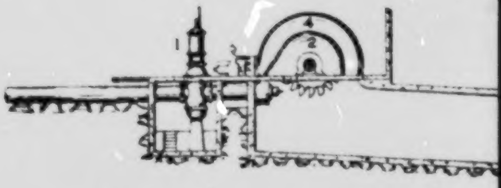

SPILLWAY
RESERVOIR
INTAKE STRUCTURE
DAM
TUNNEL
SURGE CHAMBER

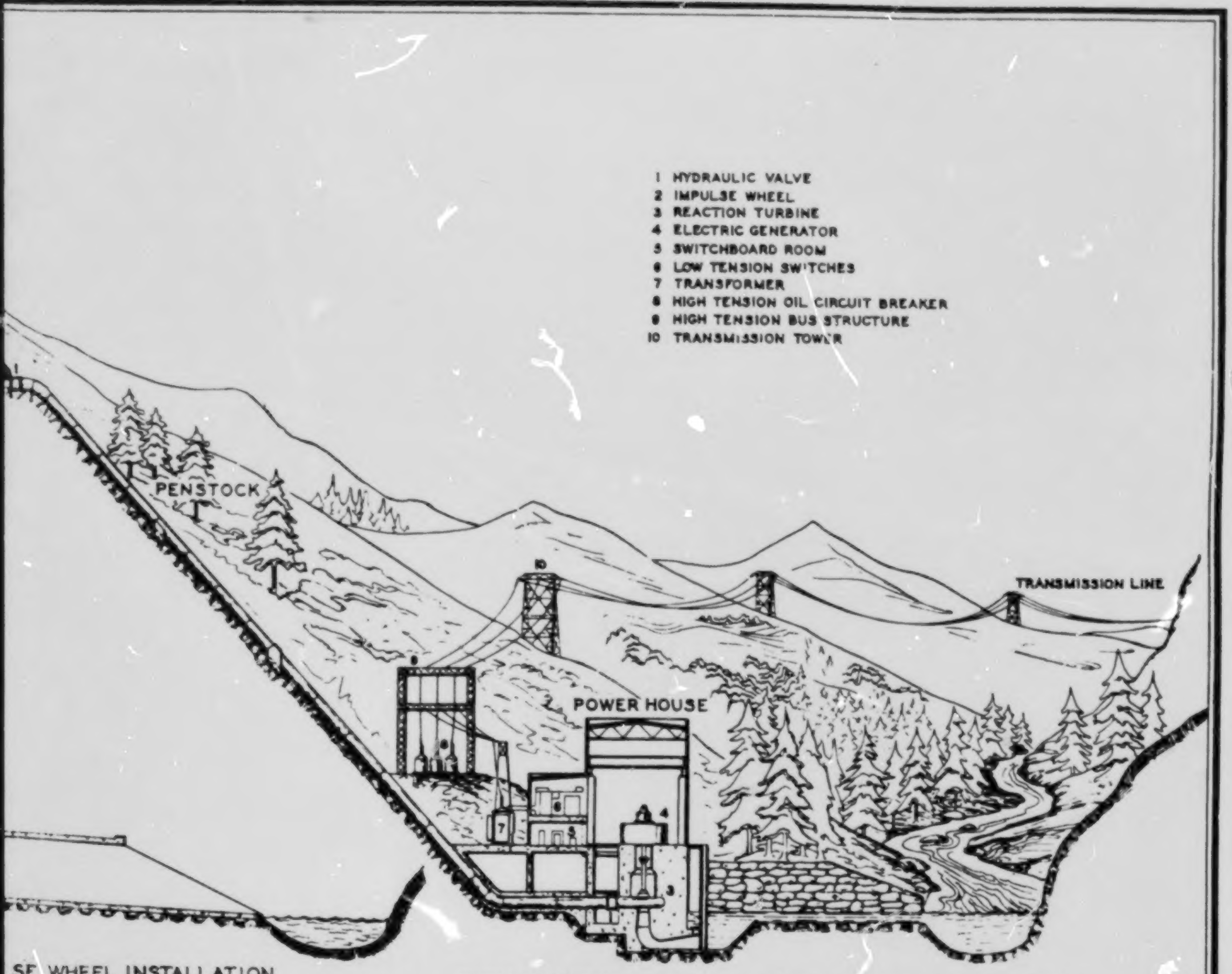
Figure 6-2

DIAGRAM OF
MODERN HYDRO-ELECTRIC DEVELOPMENT

PACIFIC GAS AND ELECTRIC COMPANY
CALIFORNIA



TYPICAL HIGH HEAD IMPULSE WH


1 HYDRAULIC VALVE
2 IMPULSE WHEEL
3 REACTION TURBINE
4 ELECTRIC GENERATOR
5 SWITCHBOARD ROOM
6 LOW TENSION SWITCHES
7 TRANSFORMER
8 HIGH TENSION OIL CIRCUIT BREAKER
9 HIGH TENSION BUS STRUCTURE
10 TRANSMISSION TOWER
PENSTOCK
POWER HOUSE
TRANSMISSION LINE
1
2
3
4
5
6
7
8
9
10

LSE WHEEL INSTALLATION

TYPICAL MEDIUM HEAD REACTION TURBINE INSTALLATION

The efficiency of modern hydro turbines ranges from 85% to 93%. Generator efficiency is about 98%. The two efficiencies multiplied provide an index to the overall efficiency of hydroelectric units. The overall efficiency of a modern thermal plant is about 40%. Not only are hydro facilities the most efficient of our conversion systems, but they are also nonconsumptive of water.

Conventional hydro facilities may be of two basic types. In the first, the power plant is constructed adjacent to or inside the base of the dam which impounds the water. Examples of this type in California include units at Shasta, Folsom and Exchequer Dams.

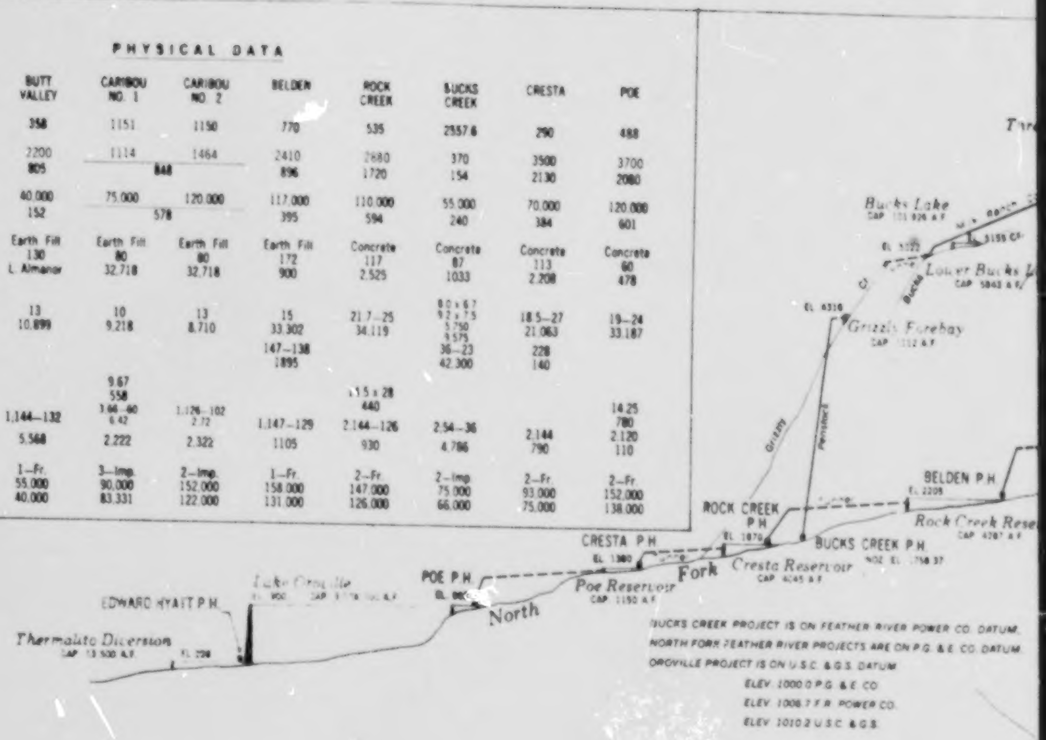
The second type uses a dam to impound water, either in a canyon or narrow impoundment area, with a tunnel or penstock carrying the water to a power house for delivery to the turbine and generating units. Numerous examples of this type of system are found in California, e.g., the systems along the Feather, American and Kings Rivers.

A relatively recent addition to the hydroelectric family is the "pumped storage" facility. In actuality, pumped storage differs only slightly from the conventional hydro unit, but this difference offers an important energy and water-saving distinction.

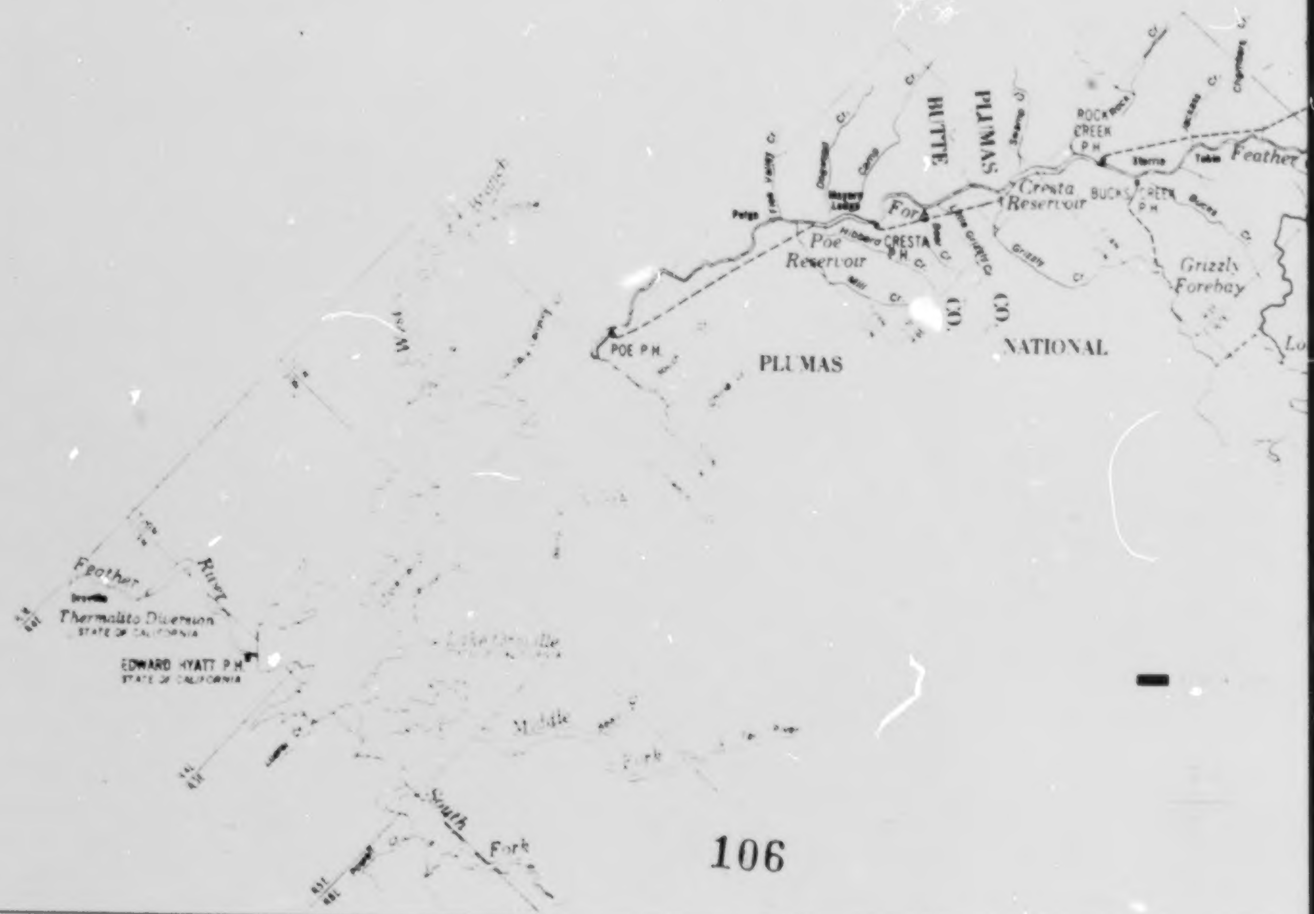
Pumped storage facilities require two holding areas, above and below the pumped storage power plant. Water is impounded after passing through the turbines and then is pumped back into the forebay, or reservoir, by reversing the turbines to make them powerful pumps. Thus, the water can be "recycled" for additional electric generation.

PHYSICAL DATA

	HAMILTON BRANCH	BUTT VALLEY	CARIBOU NO. 1	CARIBOU NO. 2	BELDEN	ROCK CREEK	BUCKS CREEK	CRESTA	POE
HEAD									
Static—ft.	409.7	358	1151	1150	770	535	2557.6	290	488
FLOW									
Peak—c.f.s.	200	2200	1114	1464	2410	2680	370	3500	3700
Average—c.f.s.	105	805	848		896	1720	154	2130	2080
OUTPUT									
Peak—kw.	4,800	40,000	75,000	120,000	117,000	110,000	55,000	70,000	120,000
Energy—million kwh. per yr.	26	152	578		395	594	240	384	601
DIVERSION									
Dam Type	Timber	Earth Fill	Earth Fill	Earth Fill	Earth Fill	Concrete	Concrete	Concrete	Concrete
Height—ft.	25	130	80	80	172	117	87	113	60
Effective Capacity—A.F.		L. Almanor	32,718	32,718	900	2,525	1033	2,208	478
CONDUIT									
Flume & Canal Length—ft.	17,300								
Tunnel size—ft.		13	10	13	15	21.7—25	8.0 x 6.7 9.2 x 7.5	18.5—27	19—24
length—ft.		10,899	9,218	8,710	33,302	34,119	5,750 9,575	21,063	33,187
Pipe dia.—inches					147—138		36—23	228	
length—ft.					1895		42,300	140	
PENSTOCK									
Tunnel dia.—ft.			9.67			11.5 x 28			14.25
length ft.			558			440			780
Pipe No. and dia.—inches	1,60—48	1,144—132	3,66—60 6,42	1,126—102 2,72	1,147—129	2,144—126	2,54—36	2,144	2,120
length—ft.	2,219	5,568	2,222	2,322	1105	930	4,786	790	110
INSTALLATION									
Number of Units & Type	2—Fr.	1—Fr.	3—Imp.	2—Imp.	1—Fr.	2—Fr.	2—Imp.	2—Fr.	2—Fr.
Total Prime Mover—H.P.	7,200	55,000	90,000	152,000	158,000	147,000	75,000	93,000	152,000
Total Generator—kva.	6,530	40,000	83,331	122,000	131,000	126,000	66,000	75,000	138,000


Bucks Lake
Lower Bucks L
Grizzly Forebay
BELDEN P.H.
Rock Creek Rese
ROCK CREEK P.H.
CRESTA P.H.
BUCKS CREEK P.H.
Cresta Reservoir
POE P.H.
Poe Reservoir
Fork
North
Lake Oroville
EDWARD HYATT P.H.
Thermalito Diversion

BUCKS CREEK PROJECT IS ON FEATHER RIVER POWER CO. DATUM.
NORTH FORK FEATHER RIVER PROJECTS ARE ON P.G. & E. CO. DATUM
OROVILLE PROJECT IS ON U.S.C. & G.S. DATUM
ELEV. 1000.0 P.G. & E. CO.
ELEV. 1006.7 F.R. POWER CO.
ELEV. 1010.2 U.S.C. & G.S.


BUTTE
PLUMAS
ROCK CREEK P.H.
Feather
Cresta Reservoir
BUCKS CREEK P.H.
CRESTA P.H.
Poe Reservoir
Grizzly Forebay
POE P.H.
PLUMAS
CO.
CO.
NATIONAL
Feather
River
Thermalito Diversion
STATE OF CALIFORNIA
EDWARD HYATT P.H.
STATE OF CALIFORNIA
Lake Oroville
Middle
Fork
South
Fork

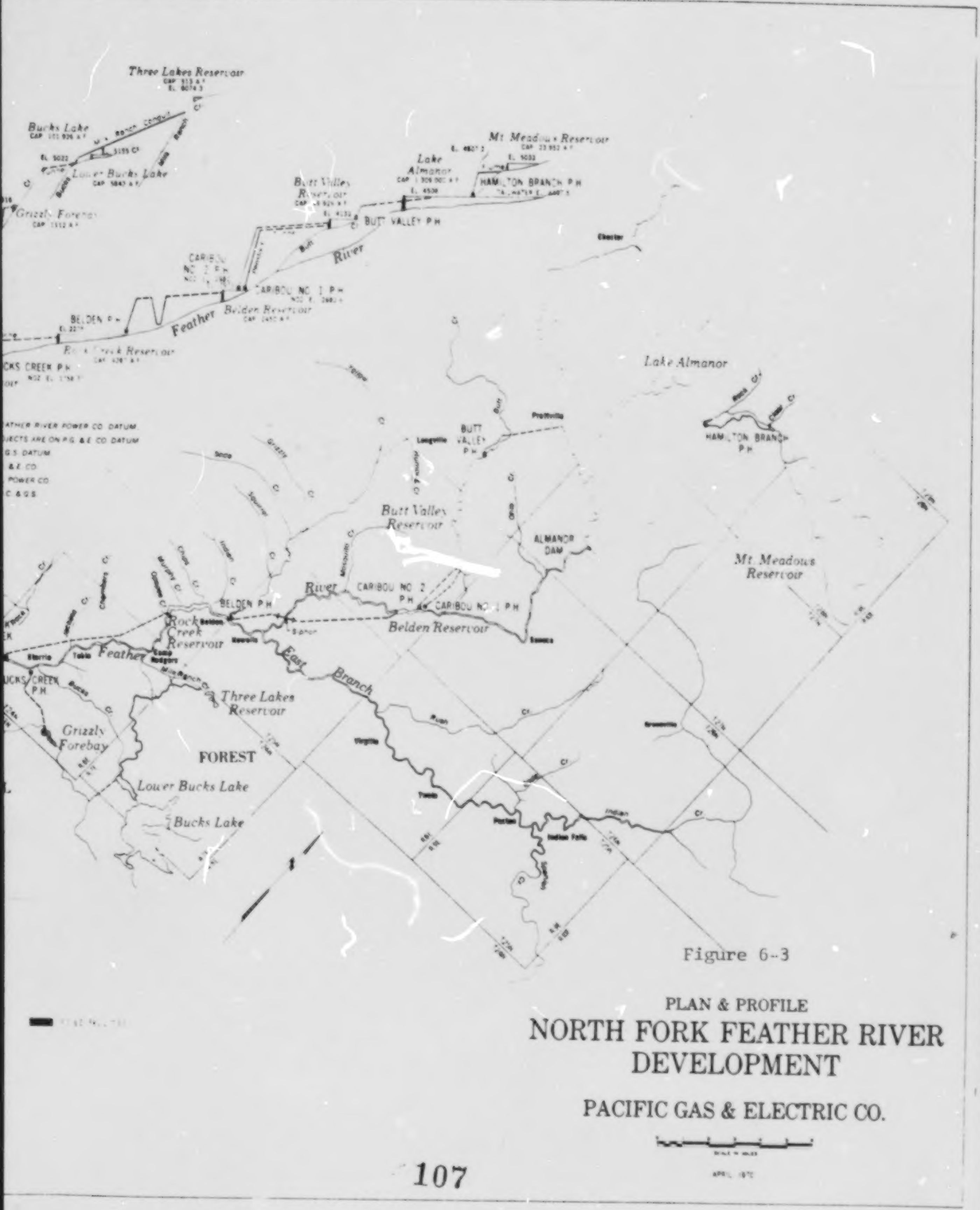
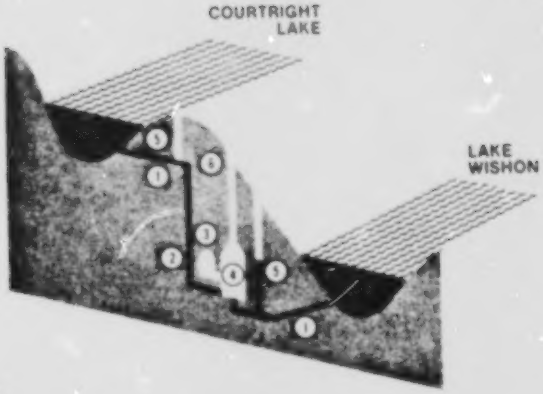

Three Lakes Reservoir
Bucks Lake
Lower Bucks Lake
Grizzly Forebay
Butt Valley Reservoir
Lake Almanor
Mt Meadows Reservoir
HAMILTON BRANCH P.H
BUTT VALLEY P.H
CARIBOU NO. 2 P.H
CARIBOU NO. 1 P.H
Belden Reservoir
BELDEN P.H
Rock Creek Reservoir
BUCKS CREEK P.H
Feather
River
Chester
Prattville
ALMANOR DAM
East Branch
Indian Falls
FOREST
PLAN & PROFILE
NORTH FORK FEATHER RIVER DEVELOPMENT
PACIFIC GAS & ELECTRIC CO.
APRIL 1970

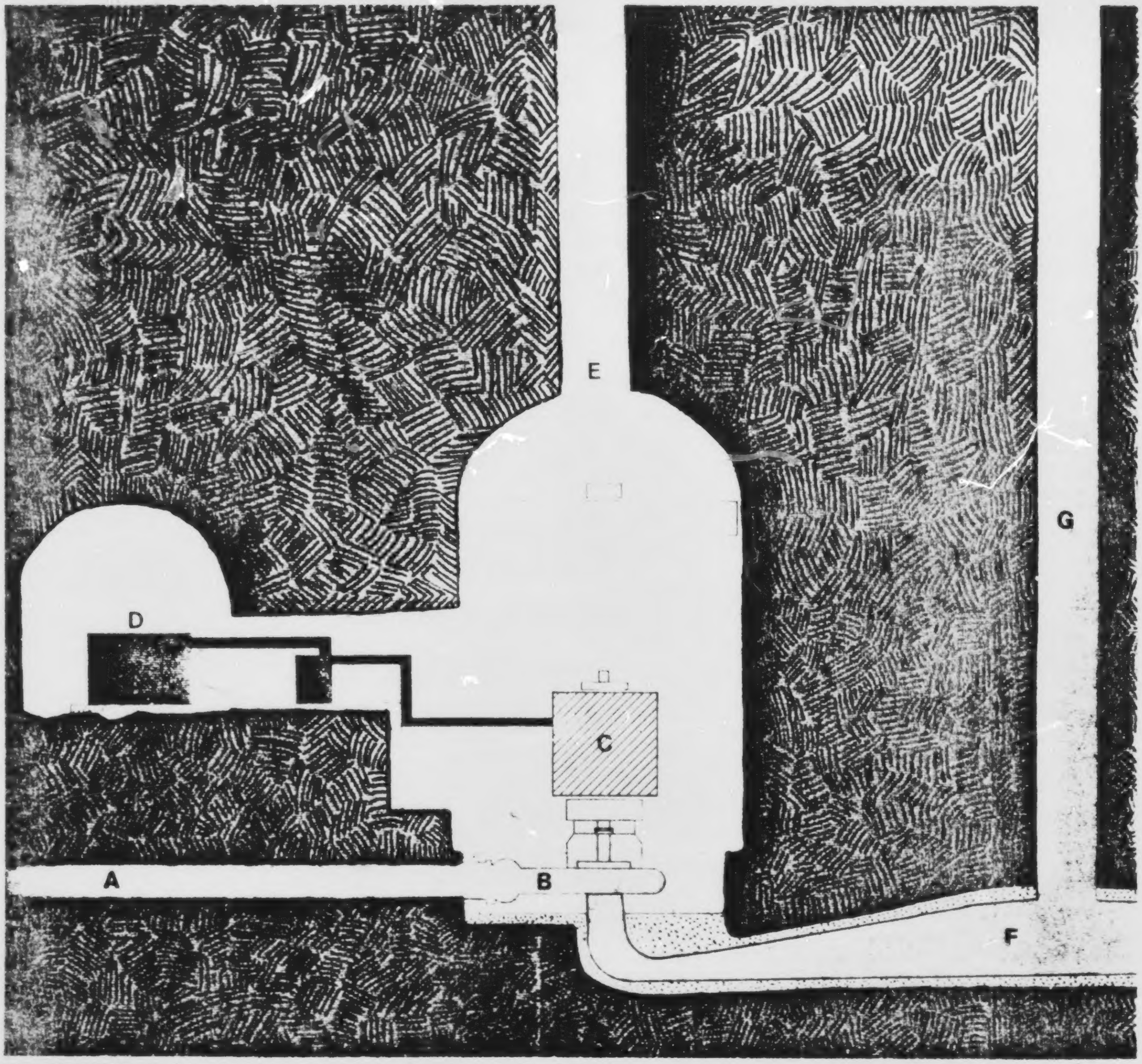
Figure 6-3

Figure 6-4



PUMPED STORAGE–This three-dimensional drawing shows some of the key features of Pacific Gas and Electric Company's pumped storage hydroelectric project on the North Fork Kings River. Total generating capacity of three reversible pump-turbines in the underground power plant will be 1,125,000 kilowatts. Indicated by the numbers in the drawing are: 1. tunnels; 2. penstock; 3. transformers; 4. generator; 5. surge chambers; 6. switchyard elevator.

Figure 6-5



Interior of proposed underground Helms Powerhouse – **A.** Penstock. **B.** Pump/turbine. **C.** Generator/motor. **D.** Transformer. **E.** Switchyard elevator. **F.** Tunnel. **G.** Lower surge chamber.

Pumped storage units generate during the daylight hours of highest energy demand. During the offpeak periods, primarily during the late evening and early morning hours, "surplus energy" is used to "recycle" the water from the storage afterbay back into the forebay. The following day, as needs dictate, water in the upper reservoir is again released to generate power to service the peak electric needs of customers.

Examples include the San Luis Project near Los Banos, the Castaic Power Plant near L.A. on the State Water Project and Helms Pumped Storage Project on the Kings River (now under construction).

This reversing of the flow of water does not come without a penalty, however. The rule-of-thumb cost for calculating the efficiency of pumped storage is that approximately three kilowatts of off-peak pumping energy are required to generate two kilowatts of peak energy to be made available to consumers. The electrical efficiency of the system then is approximately 67%.

The primary advantage of pumped storage is that water can be recycled many times, thus greatly extending the generating capability of water which can be used only once in conventional hydro systems. Perhaps equally important, the strategy acts as a load-leveling procedure which enables utilities to substitute cheaper off-peak energy, such as nuclear or coal, for high-cost peaking power.

Supporters of hydroelectric units cite the following as significant advantages:

1. Relatively low total environmental impact.
2. Extremely high overall efficiency (for conventional plants).
3. Low operation and maintenance requirements.
4. Nonconsumptive in terms of resources; with the exception of pumped storage units, no external energy is required.
5. Long periods of high productivity.
6. High net energy yield.
7. Easily adapted for automatic operation and control.
8. Quick "startup" time required; peak loads quickly accepted.
9. Multiple use capabilities, i.e., water storage, flood control, recreation and electric generation.

Disadvantages associated with hydroelectric facilities include the following:

1. Limited siting opportunities; must be built where the resource occurs.
2. Interruption of natural stream flow characteristics.
3. Alteration of the habitat for both aquatic and terrestrial organisms.
4. Area inundation and subsequent loss of productive acreage.
5. Disruption of wildlife migrations.
6. Distance from load centers forces higher transmission costs and line losses.
7. Aesthetic penalties from constructing dams and related facilities in forest areas.

Potential energy, abbreviated P.E., is the capacity of a body or material to perform work by virtue of its position. The equation for expressing potential energy is P.E. = weight x height. In the case of a hydroelectric facility, water impounded behind the dam, but not moving vertically, possesses potential energy by virtue of its position.

If the force restraining the object or material is suddenly released, and the body starts to fall in response to the pull of gravity, potential energy becomes kinetic energy. In a hydro unit, water moving through the penstock on its way to the turbines possesses kinetic energy.

If we were interested in calculating the energy potential of 1,000 lbs. of water impounded 200 ft. above the ground, we would use the equation noted: P.E. = 1,000 x 200 = 2 x 105 ft. lbs. In examining the equation, it is apparent that as the height of a given mass of water increases or decreases, the potential energy changes.

In considering dam construction, and assuming a given volume of water, it's apparent that the higher the dam, the greater the potential energy of the impounded water and the larger the energy yield which can be anticipated.

Energy calculations are usually less concerned with potential energy than with the actual expected energy yield, or power. Addition of the power factor adds another unit, time. Calculation of the power developed by a specific hydro unit would require knowledge of the volume or weight of the water released, the height or distance between the water and the point where work is to be performed and the rate at which it is released. An equation to calculate the power of the turbine is as follows:

Potential Energy (P.E.) = weight in lbs. (W) x height in ft.

Power: measured in foot lbs./second

$$\text{Power} = \frac{PE}{T} = \frac{H \cdot W}{T} \text{ with } \begin{array}{l} W \text{ (weight)} = 62.4 \text{ Vol. in cu. ft.} \\ H \text{ (height) in feet} \end{array}$$

$$= \frac{HwV}{T} = Hw\frac{V}{T} = HwQ \text{ where } \frac{Q}{T} = \frac{\text{Vol. (in cubic feet)}}{\text{time in seconds}}$$

To account for friction losses and turbine inefficiencies, multiply P_w x turbine efficiency (E_t, Gr. Epsilon) = Power_t (turbine)

$$P_t = P_w \times E_t$$

$$P_t = \frac{E_t\ H.Q.62.4}{550}$$

(H = head in feet
(Q = Volume rate in cubic feet
(62.4 = weight of 1 cubic foot H_2O
(550 ft. lbs./sec - 1 horsepower

$$= \frac{E_t\ .H.Q}{8.8} \text{ in HORSEPOWER (HP)}$$

Example "A": 4000 cfs at 650 foot head

$$E_t = 90\%$$

$$P_t \text{ (in horsepower)} = \frac{.90 \times 650 \times 4000}{8.8}$$

$$= 266{,}000 \text{ HP}$$

To determine the part of a generator attached to the turbine:

$$P_t = P_t \times E_g$$

Assuming Eg = 96%, using prior example,

P_t = 266,000 HP
E_g = .96
P_g = 266,000 x .96
= 255,360 HP

If 746 watts = 1 HP then 1 KW = 1.34 HP

How many KW are produced by the unit in example "A"?

$$\frac{255{,}360 \text{ HP}}{1.34} \text{ (at the generator)} = 190{,}567 \text{ KW}$$

As the supplies of our traditional fuels decline and the pressures for energy increase as a consequence of population increases, it is likely that changes in technology and longer use of existing facilities can increase energy produced by hydro facilities. By the end of 1970, slightly more than 53,000 megawatts of hydroelectric capacity had been developed in the U.S. In round figures, the Federal Energy Administration estimates that 125,000 megawatts of capacity remain, some 30,000 megawatts of which are in Alaska.

Such figures can be misleading, for it's a fact that the large majority of the truly appropriate hydro sites in this country have either been developed or are in areas of environmental significance. Some of the better sites in the Pacific Northwest and in California are protected through legislation prohibiting further development. Globally, the situation is much more promising, with something less than 1/10 of the world's hydro power potential tapped.

CHAPTER 7

PETROLEUM

Petroleum, contributing 46% to the total U.S. energy scene, is our largest single source of energy. Within that 46%, transportation, including automobiles, utilizes 55%; space heating, 20%; process heat, 11%; petrochemicals, 10%, and electric energy generation, 6%.

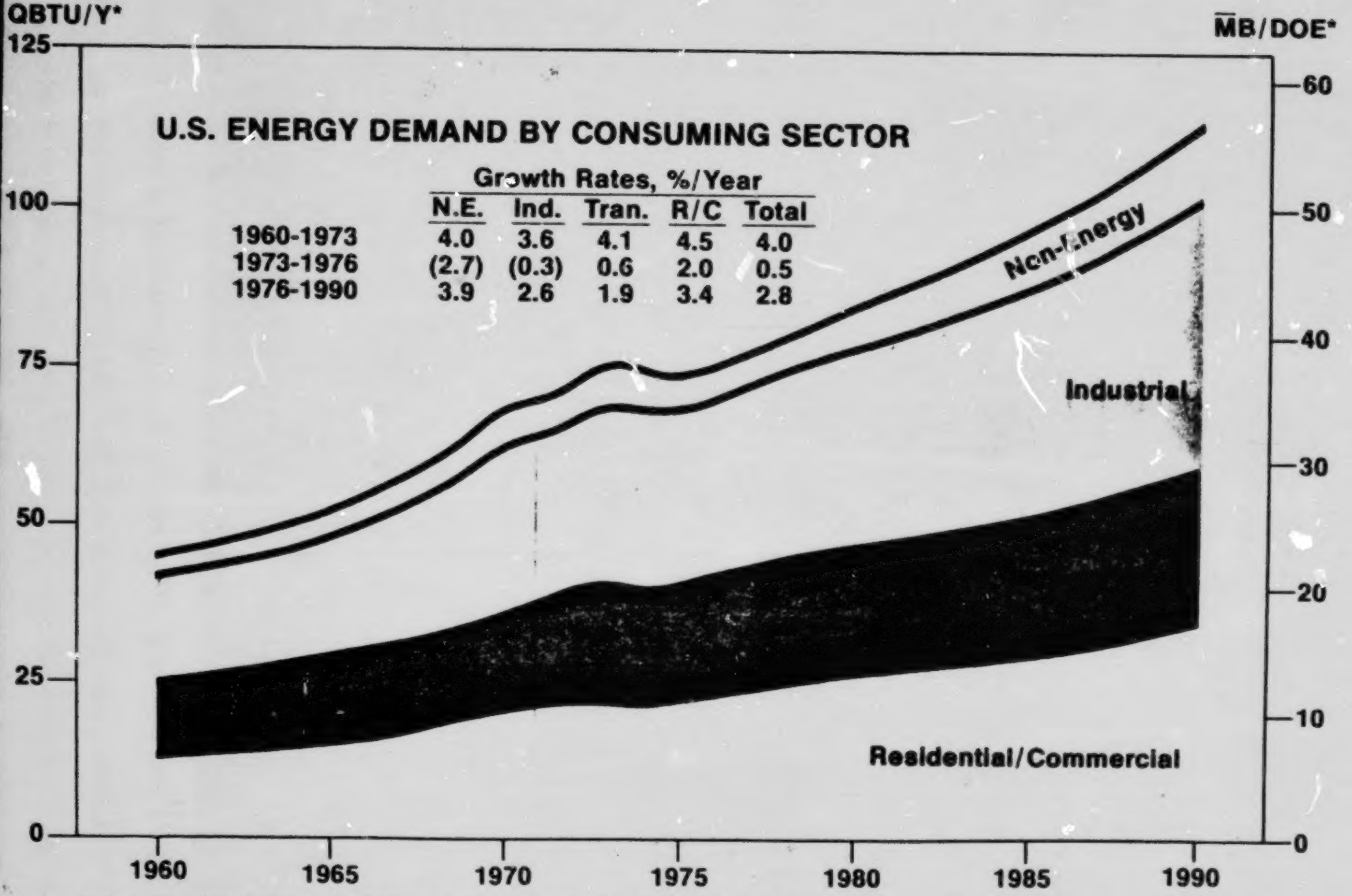
Scientists are in general agreement that prehistoric plants, along with a minor contribution by animals, are the foundation of today's petroleum deposits. The circumstances in the development of these deposits were varied and included large, relatively warm bodies of water where living organisms could multiply, complete their life cycles and be covered by sand and porous rock which itself would be subjected over millions of years to intense heat and pressure.

Specific geologic structures, termed anticlines and synclines, provided collection points where oil could migrate to be recovered by today's sophisticated drilling techniques. Petroleum deposits are likely to be located only in specific areas of the globe, a fact which appears to be attested by the California experience.

Examination of the oil fields within the state shows that the Kern-Taft-Elk Hills area was covered by ancient inland seas. Long periods of submergence, during which associated plant and animal life settled and accumulated, produced the rich oil deposits which have contributed so much to the state's economy.

U.S. oil consumption today stands at about 18 million barrels per day. Since 1970, domestic use of petroleum has increased at a rate of about 1 million barrels per day annually. In 1974, U.S. energy use was equivalent to nearly 38 million barrels per day. (Here, the term, "equivalent," means simply that if all energy resources were converted to oil, the total would be 38 million barrels a day.) (Figure 7-1)

Figure 7-1



U.S. ENERGY DEMAND BY CONSUMING SECTOR

	Growth Rates, %/Year				
	N.E.	Ind.	Tran.	R/C	Total
1960-1973	4.0	3.6	4.1	4.5	4.0
1973-1976	(2.7)	(0.3)	0.6	2.0	0.5
1976-1990	3.9	2.6	1.9	3.4	2.8

*2 Quadrillion British Thermal Units/Year = 1 Million Barrels/Day Oil Equivalent

Barrels of oil per day equivalent (BOPDE) is of particular importance in that it provides not only a single figure which conveys the total energy needs in the U.S., but it also serves as a yardstick against which other individual energy resource contributions can be easily compared.

On the basis of calculations by resource authority, M. King Hubbert, U.S. proved petroleum reserves will drop essentially to zero by 2025; globally, petroleum will, for all practical intents and purposes, be exhausted by 2075. Petroleum production in the U.S., exclusive of Alaska, is declining significantly. Hubbert's exhaustively documented estimates seem to demonstrate rather conclusively that his projections about petroleum, while ominous, are to be believed. (See Figures 3-2, 3-3, & 3-4)

Resource base represents the total amount of petroleum physically present, whether recoverable or not. The total U.S. petroleum resource base, as of 1970, was estimated to be 2,830 billion barrels. Of that amount, 1,360 billion barrels, or 48%, is located "offshore" on the continental shelf.

Petroleum reserves is the amount of petroleum recoverable with reasonable certainty under existing technological and economic conditions. The U.S. petroleum reserves as of January 1, 1974, were estimated at 35.3 billion barrels.

Life index (L.I.R.) expresses a ratio of the estimated lifetime of proven reserves to annual production. For U.S. petroleum, calculation of the life index would involve dividing the 3.2 billion barrels of petroleum produced annually into the 35.3 billion barrel proved reserves, yielding a life index ratio of approximately 11:1.

A life index figure for petroleum, or any other energy resource, projects succinctly and precisely the estimated longevity of that particular energy form. With a petroleum life index of 11:1, it's clear that continued consumption of petroleum at present rates is both unwise and indicative of the urgent need to develop alternative forms of energy.

Domestic production in 1975 came to about 9.6 million barrels per day. Comparison of that production rate with the nearly 18 million barrels per day of petroleum consumed within the U.S., shows a daily deficit of more than 8M/B/D. Who is responsible? A number of factors are in operation.

The two of greatest significance are the nation's continued population increase and the increase in per capital energy use. Those factors are compounded by declining supplies of natural gas, forcing a switch by many industries and utilities to petroleum as an energy source. Further complications are the limited availability of low sulphur coal and the requirement for automotive emission devices which have a profound negative effect on the efficiency of internal combustion engines.

It's estimated that automobiles produced in 1972 required 300,000 more barrels of petroleum each day than 1971 models for the same number of miles traveled. This was solely because of emissions controls which decreased engine efficiencies. It remains to be seen whether EPA's imposition of what some perceive as short-term, ill-considered environmental protection requirements constitutes a reasonable approach to better utilization of energy resources.

The petroleum industry has traditionally responded to declining petroleum availability by increased exploration, both onshore and in the more demanding environment of the continental shelf. Unfortunately, drilling for deeper deposits and rigorous standards of environmental protection involve increased expenditures of money. Until recently the price for domestic oil apparently did not justify the costs associated with higher risk exploration.

The OPEC petroleum embargo and a subsequent increase in the price of domestic oil have helped to spur increased interest in petroleum exploration. Although the increased activity can be expected to provide significant new discoveries, it appears that the most promising oil fields have already been identified.

To anticipated new discoveries can be added some anticipated increases in petroleum recovery rates. The average recovery rate for a domestic oil field is approximately 33%, leaving essentially 2/3 of the petroleum intact within these oil bearing strata. Petroleum engineers are in general agreement that oil recovery rates from existing wells can be improved significantly.

While some predict that technology can increase the "take" to approximately 60%, the majority of geologists and petrologists feel that recovery will remain significantly less. Some, in fact, hold that even with modern recovery techniques, "net energy" yield will be marginal and may in many cases require energy inputs in excess of increased yields. The appeal of increased returns through improved technology is persuasive, however, and extensive research and effort are under way to improve existing recovery rates.

A bit of mental gymnastics will demonstrate that increasing the existing recovery rate from 30% to 45% could extend significantly the availability of domestic petroleum. The ultimate net energy yield of the different processes can only be determined empirically.

Effort toward extending petroleum exploration and improving recovery is being accompanied by an accelerated research program designed to increase the availability of oil in shale and sands. Shale is a layered, sedimentary rock in which plants and animals were trapped and evenly distributed throughout the sedimentary mass. (See Figure 7-2)

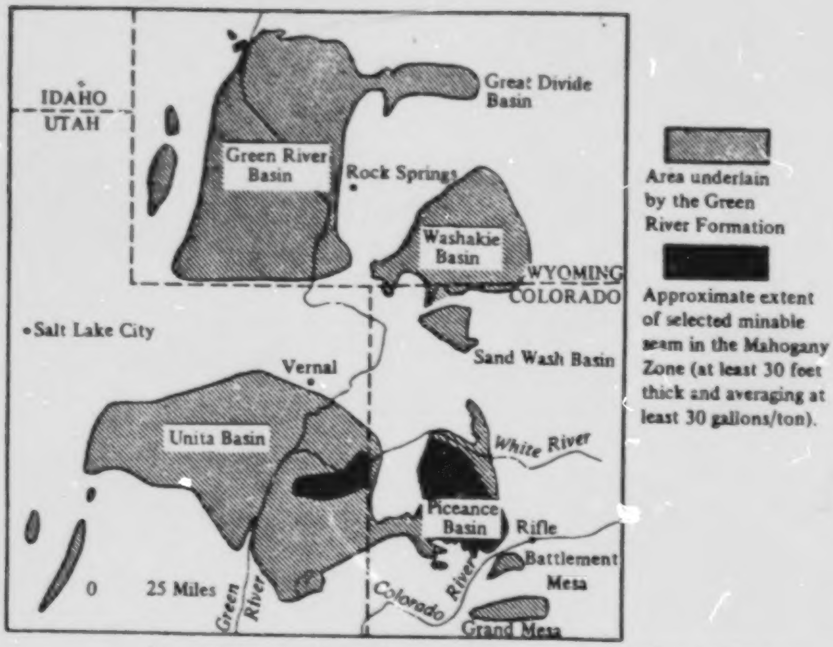
This has produced a reddish brown rock which, upon casual examination, conveys no impression that it might contain petroleum. The oil-bearing Kerogen in shale, however, is so diffusely distributed that even in a good quality shale deposit, little more than one-half-barrel of oil per ton of material processed will result.

In the U.S., the major shale oil deposits are in Colorado, Utah and Wyoming in a geologic structure identified as the Green River formation. Resource estimates vary extensively. The highest suggest that possibly 600 billion barrels of oil may be available.

Unfortunately, technology for the economic recovery of this shale oil does not presently exist. Perhaps more unfortunately, a major fraction of the 1/2+ barrel of oil per ton of shale must be utilized in the mining and extraction. An important consequence of this energy requirement is that the net energy yield of petroleum produced from shale is under many circumstances subject to question.

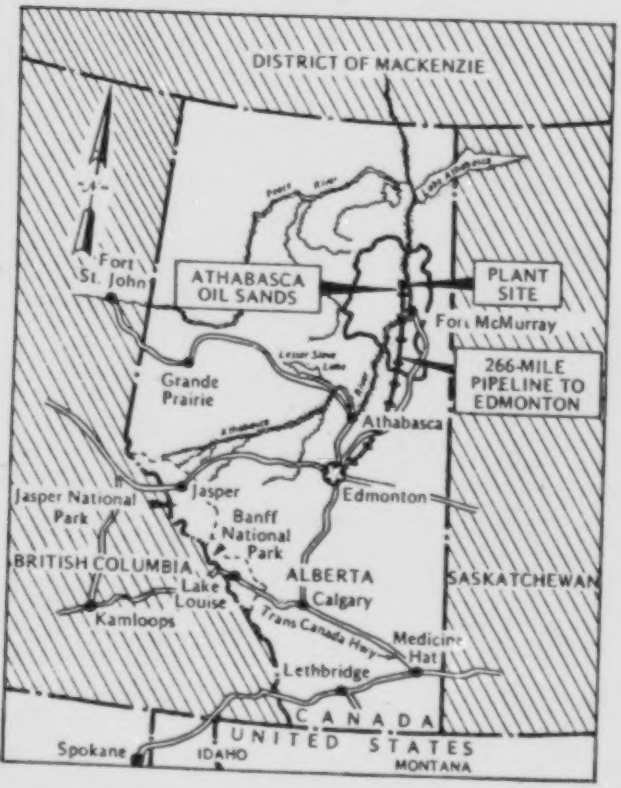
Although procedures vary, the typical production of oil from shale includes mining from surface areas, crushing, and cooking in a cylindrical, constant-feed retort where the pulverized shale is heated in the virtual absence of oxygen to temperatures approaching 500°C. Condensation of the vaporized material produces a synthetic crude oil. Research is continuing into the possibility of

Figure 7-2


IDAHO
UTAH
Great Divide Basin
Green River Basin
Rock Springs
Washakie Basin
WYOMING
COLORADO
Salt Lake City
Sand Wash Basin
Vernal
Unita Basin
White River
Piceance Basin
Rifle
Battlement Mesa
0 25 Miles
Green River
Colorado River
Grand Mesa
Area underlain by the Green River Formation
Approximate extent of selected minable seam in the Mahogany Zone (at least 30 feet thick and averaging at least 30 gallons/ton).

Large oil shale resources are concentrated in the prehistoric lake beds of these four basins in Wyoming, Colorado, and Utah. (Source: A Summary Report of the National Petroleum Council's Committee in U.S. Energy Outlook, *op. cit.*)

Figure 7-3


DISTRICT OF MACKENZIE
Peace River
Lake Athabasca
Fort St. John
ATHABASCA OIL SANDS
PLANT SITE
Fort McMurray
Lesser Slave Lake
266-MILE PIPELINE TO EDMONTON
Grande Prairie
Athabasca
Edmonton
Jasper
Jasper National Park
Banff National Park
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
Lake Louise
Calgary
Kamloops
Trans Canada Hwy
Medicine Hat
Lethbridge
CANADA
UNITED STATES
Spokane
IDAHO
MONTANA

Athabasca tar sand location, Alberta, Canada.

extracting the oil from shale in situ, thereby avoiding many of the environmental and aesthetic difficulties associated with surface or deep mining operations.

The practical significance of in situ processing is that facilities capable of producing 1 million barrels of shale oil per day may prove to be feasible. That would require the processing nearly 2 million tons of shale per day which, in combination with a 12% expansion of the "ore," would pose an environmental and disposal problem of formidable dimensions.

Despite some of the economic-environmental challenges noted, many researchers are of the opinion that with continued research and improvement on existing extraction procedures, oil shale can and will play an important role in providing liquid petroleum for the U.S. in the future.

Tar sands, although available in much smaller quantities than oil shales, and located for the most part near Athabaska in northern Alberta, Canada, constitute still another source of liquid petroleum. The Athabaska tar sand deposits contain an estimated 300 billion barrels of recoverable petroleum. As the name "tar sands" suggests, the material possesses the general appearance of the bituminous mix so generally used for the surfacing of roads and parking lots. (See Figure 7-3)

Not surprisingly, the processing of this extremely viscous material poses some formidable problems. Motorized and mobile extraction equipment is confronted in the hot summer months with a sticky, gooey material that's extremely difficult to dislodge from buckets and elevating equipment; in the winter the reverse holds. Instead of having to work with a tar-like material, the cold temperatures transform the tar into a rock-hard mass, making extraction extremely difficult. Extraction of the petroleum from the sands utilizes a process not unlike that used for extracting petroleum from oil shale.

Today, about 50,000 barrels of tar sands oil are produced daily, with a significant component of that exported to the U.S. Studies suggest that production could be increased materially. At least one obstacle between tar sands and a prominent role in meeting the energy needs of the U.S. is the recent decision by the Canadian government to limit exports of both petroleum and natural gas, pending determination of Canada's own long-term energy needs. This could mean that Athabaskan tar sands, however productive, may not be of usefulness to the U.S.

With some background on the forms of petroleum, their distribution and availability, and the obstacles involved in harnessing some of the new petroleum forms, we can now turn our attention to another area - petroleum usage. In the U.S. the major use categories are the generation of electricity and transportation.

The process in which chemical energy from in fossil fuels is converted to kinetic energy (steam) and then to mechanical energy in a steam turbine is anything but new. It dates back to the first century A.D.

Large-scale use of steam engines gathered momentum in the 1700's with the introduction of steam-powered water pumps in the coal mines of Great Britain. From that relatively modest beginning, steam-powered equipment made its way to ships, railroads, automobiles and, most prominently today, to massive, highly efficient steam turbines used for the generation of electrical energy.

The basics by which steam is generated involve (1) the introduction of fossil fuels to a combustion chamber (2) routing of combustion products through the upper sections of the boiler, and (3) converting water pumped through boiler tubes into steam. The steam in turn is routed outside the boiler to a turbine or cylinder where its kinetic energy is transformed into mechanical energy.

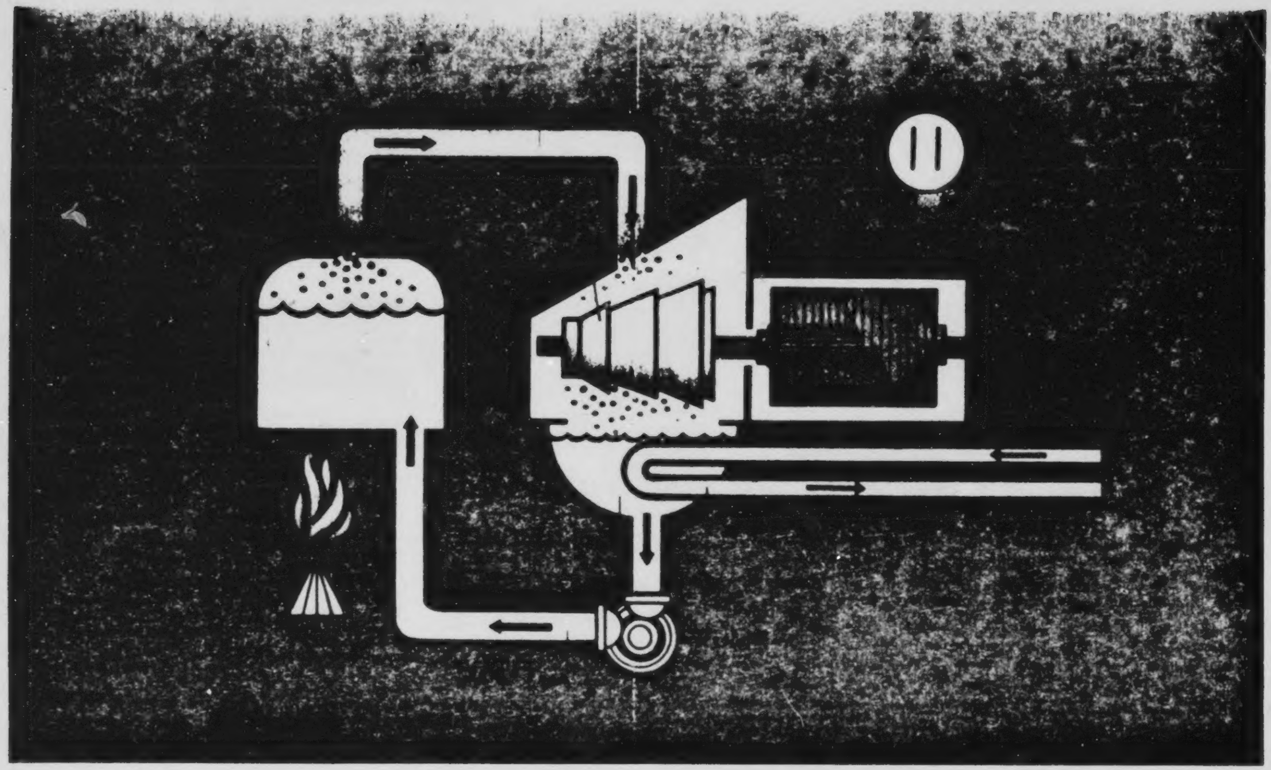
Routed through a condenser, the steam condensate is pumped back to the boiler where it is reheated and the process repeated. Full appreciation of the complexities, engineering and technology of a modern steam plant requires an understanding of each of the components involved in the combustion and energy conversion processes. (Figure 7-4)

Transportation, the second largest consumer of energy in the United States, utilizes about 25% of total U.S. energy and about 55% of the petroleum used each year. Fuel accounts for about 99% of the petroleum utilized in transportation; 1% goes into lubricants. Fuel consumption in transportation is affected by vehicle weight and engine displacement and, to a lesser although still significant extent, by driving habits, vehicle condition and driving conditions.

The upper part of Fig. 7-5 shows a carburetor, the basic function of which is to convert liquid gasoline into an easily burned vapor. This is accomplished by a series of metering devices which mix gasoline with air at a ratio of 16 to 1 by weight. On modern vehicles, the fuel-to-air ratio is adjusted automatically to accommodate changing conditions of speed, load, temperature and altitude. A ratio of 16:1 (air to fuel by weight) represents the proportion where desirable flame-propagation and essentially complete combustion occur.

From the carburetor, the vaporized fuel travels through the intake manifold and valves to the cylinder where a piston compresses the air-fuel mixture to a fraction of its original volume; a compression ratio of

Figure 7-4



Steam-electric power plant

approximately 8:1 is commonplace. Near the "top dead center" of the piston stroke, a spark of from 20,000 to 30,000 volts travels between the electrodes of a sparkplug to ignite the fuel-air mixture.

Under conditions of proper operation, the flame front initiated by the spark travels through the fuel-air mass gradually, consuming the fuel, expanding the mixture within the cylinder and forcing the piston to the bottom of the stroke. Valve timing introduces the fuel intake mixture at the proper time and assists in expelling the burnt combustion mixture to the exhaust manifold and the muffler.

The crankshaft at the lower part of Fig. 7-5 transfers the linear energy of the piston and connecting rod to rotary motion. Relatively simple and rugged and adaptable to a variety of conditions, the gasoline-fueled internal combustion engine represents the mainstay of U.S. private transportation.

Efficiency of operation of these engines is affected by the compression ratio, i.e., the higher the compression ratio the more efficient the engine, but high compression ratios introduce additional problems -- greater cooling requirements or the need for lead additives to reduce the tendency of fuel mixtures to explode rather than burn.

The design of the combustion chambers, the metals used in the head and cylinder walls and the valve timing all affect power output, overall efficiency and utility. Despite long-term efforts to increase the efficiency of internal combustion engines fueled by gasoline, the engine efficiencies remains at about 10% to 12%.

The characteristics of the exhaust gases are worthy of mention. Gasoline-fueled units introduce significant quantities of hydrocarbons in the form of unburned fuel, oxides of nitrogen, oxides of sulphur, carbon monoxide and, in some cases, lead. Roughly 95% of the fuel used in gasoline-powered vehicles is lost as waste heat, with overall average vehicle efficiency approaching only 5%.

The second type of internal combustion engines of interest is the diesel (Fig. 7-6). It operates on a quite different basis and has significantly different operational and emission characteristics than the gasoline engine. The diesel engine operates at approximately 25% efficiency, at least twice that of the gasoline-fueled engine. Interestingly (and encouraging), diesel engines produce quantities of carbon monoxide and hydrocarbons which easily meet Federal emissions requirements.

Although diesel engines as a group enjoy a lower oxides of nitrogen emission rate than gasoline-fueled units, the NO_x emissions are still in excess of the EPA requirements. Part of the reason for the substantially different operational and emissions requirements rest with the fact that diesel engines use a heavier and less volatile fuel, thereby avoiding the vaporization problems associated with gasoline. While diesel fuel contains a larger number of Btu's per gallon, it contains no tetraethyl lead (there may be slightly larger amounts of sulphur).

Note the absence of both carburetion and ignition systems; eliminating those two complex components assists in providing greater reliability in diesel units. As with the gasoline-fueled engine, air is drawn into the cylinder by a downward stroke of the piston and compressed by an upward stroke of the piston.

Rather than being compressed to a ratio of 8:1 or 9:1, however, diesel fuel is compressed at an extremely high ratio, varying from 16:1 to 22:1. The consequence is that the air is heated to a temperature exceeding the combustion point of the fuel.

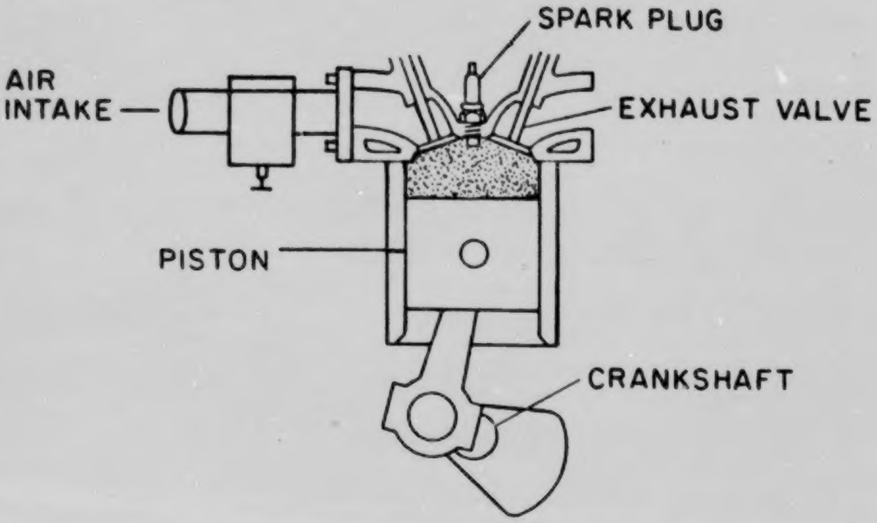
At the top of the compression stroke, diesel fuel in extremely minute quantities is introduced to the hot compressed air through an injector spray nozzle. A combination of high temperature oxygen and fuel forms a readily combustible mixture which possesses the very desirable characteristics of slow and complete burning.

One important consequence of this fuel combustion characteristic is that the piston is forced toward the crankshaft in a long power stroke which provides a more consistant pressure on the piston and a longer torque period on the crankshaft than could be achieved through the use of gasoline.

In examining the diesel, you'll note that whether under partial or complete power the volume of air introduced into the cylinder is constant. Except under the most unusual circumstances, this provides oxygen in excess of that required by the fuel. An important environmental consequence of this distinction is very low percentages of carbon monoxide and hydrocarbon emissions, thus eliminating the need for complex catalytic or after-burner systems.

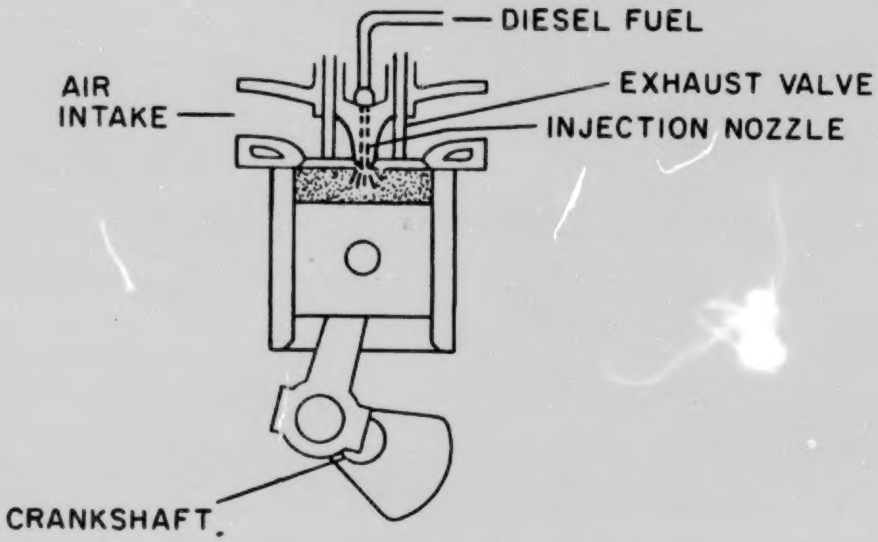
On the minus side, diesel engines are heavy, are more costly to engineer and produce, are noisy, particularly at idle speeds. Some owners say diesels smell worse than gas-fueled engines. Despite these drawbacks, many in transportation and automobile design project a rosy future for diesel engines in all forms of transportation, including private vehicles.

Figure 7-5


SPARK PLUG
AIR INTAKE
EXHAUST VALVE
PISTON
CRANKSHAFT

GASOLINE ENGINE

Figure 7-6


DIESEL FUEL
AIR INTAKE
EXHAUST VALVE
INJECTION NOZZLE
CRANKSHAFT.

DIESEL ENGINE

CHAPTER 8

NATURAL GAS

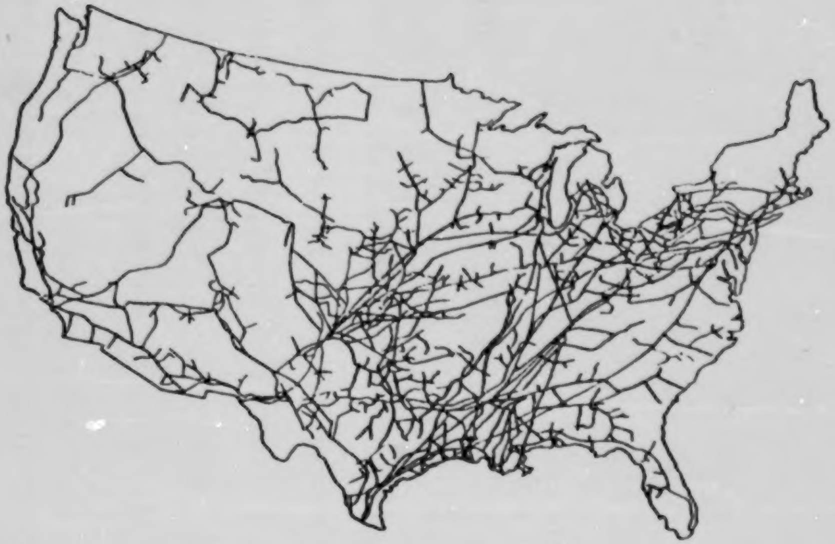
The use of combustible gases for lighting and heating traces back to the early 1800's when gas produced from coal was utilized for street lighting in London. From that beginning, the use of gas for street lighting extended to the U.S. and to other countries. Its popularity lasted until the advent of electrical energy, which proved superior for lighting.

Large-scale use of natural gas in the early stages tended to be restricted to areas near where the gas was produced. This limitation traced to the difficulty in transporting gas long distances. Improved pipeline technology, more efficient compressor units and increased demand (encouraged in the U.S. by an artificially low wellhead price) stimulated the use of natural gas wherever it was available in the industrial world. Concurrently, consumption of manufactured or "coal gas" decreased to a negligible amount.

The extent to which natural gas pipelines serviced the needs for this form of energy in the U.S. is indicated in Fig. 8-1. In 1972, natural gas provided 34% of the total energy needs in the U.S. Unfortunately, the once rosy outlook for natural gas is now clouded by the realization that production in the U.S. has peaked.

Indications are that domestic supplies of natural gas will be exhausted in the first quarter of the next century. It is ironic indeed that in many parts of the world, particularly in the Mideast and Africa, natural gas is still being burned off as an unmarketable product. Regrettably, the same conditions which prevented the early utilization of natural gas in this country now plague the oil-producing countries in other parts of the globe.

Figure 8-1



Major Natural Gas Pipelines in the Conterminous United States

Redrawn with permission from *The Story of Gas* by Elbert C. Weaver, p. 11, copyright American Gas Association, Inc.

Let's consider the physical and chemical characteristics of natural gas which combine to make it such a desirable fuel. Natural gas is primarily methane (CH_4) or "marsh gas." Methane accounts for 80% to 95% of the chemical composition of natural gas, the balance consisting of smaller amounts of related hydrocarbons such as ethane (C_2H_6) and heavier hydrocarbons such as propane (C_3H_8), butane (C_4H_{10}) and pentane. Non-combustible gases such as carbon dioxide, nitrogen, and some of the rare gases like zenon, radon, argon and helium are also occasionally present in minute quantities.

Removal of the heavier, unwanted hydrocarbons from the wet natural gas is accomplished via a purification process termed, "scrubbing." This consists of bubbling the natural gas through a series of pans containing heavy hydrocarbon oil. Products which interfere with the combustion characteristics of the natural gas are removed to improve the Btu characteristics of the processed gas. Additionally, the economically valuable components such as helium, sulphur, propane and butane are refined, purified and sold for use in other industries.

Depending upon its origin and chemical composition, natural gas is classified into one of two categories. "Wet" natural gas is formed in conjunction with the kind of petroleum deposits found in Texas, Louisiana and Southern California.

"Dry" natural gas develops in the absence of liquid petroleum. In California, the deposits in the San Joaquin-Sacramento Delta area and the northern section of the Sacramento Valley are examples of "dry" or non-associated gas. It surprises many to learn that the major natural gas deposits in California are not associated with oil-bearing strata.

Because the liquid fractions of wet natural gas introduce components undesirable to the gaseous fuel, those materials are removed and marketed as propane, butane, and other natural gas liquids. Crude natural gas is classified as "sweet or sour" depending on the quantities and characteristics of the sulphur compounds it possesses.

Compounds of sulphur in natural gas are objectionable because of the odors produced in combustion and because of sulphur's corrosion potential. Processing removes the unwanted sulphur from the crude natural gas and, in those circumstances where sulphur exists in significant quantities, it can have economic value as a by-product.

Less than 2% of all U.S. natural gas is used in the manufacture of petrochemicals and nitrogen fertilizers. Slightly more than 98% is used as a residential fuel, as fuel for industrial processes or in the generation of electrical power by utilities. However, the 2% natural gas utilization figure for petrochemicals is misleading since many of the liquid hydrocarbons removed during processing form the basis for important chemicals and related products. Residential uses, it should be noted, account for only 21.9% of natural gas consumption.

The role of natural gas in the U.S. energy mix is impressive. Although 34 states contain proven natural gas reserves, almost 90% of the total is located in just six states. Two of those, Texas and Louisiana, account for nearly 61% of all estimated proven natural gas reserves. One must remember that estimates are based on geologic data which assume favorable conditions for the accumulation of natural gas. While experience suggests that estimates have been conservative, it would be erroneous to assume that the projections are without possibility of error.

Table 8-1 confirms the location of the lion's share of the proven natural gas reserves in the southwestern U.S. Study of Column A could give the mistaken impression that natural gas resources are truly extensive. However, the considerable difference between a resource base and proven reserves indicates otherwise. The natural gas life index turns out to be about 11:1, not significantly different from domestic petroleum.

One complication in developing valid life index figures for natural gas traces to the fact that although 82% of our existing production comes from onshore wells, as much as 37% of the potential deposits lie offshore. Assuming continued improvement of offshore drilling technology and the resolution of differences between environmentalist and the petroleum industry, the life index ratio could well be extended considerably.

Since 1955, domestic resources have been increasingly supplemented by imports from Canada and Mexico. The 1973 contribution was about 4%. It appears unlikely that imports from the two areas will increase significantly. Mexico, apparently, has no plans underway to increase exports of natural gas, and Canada has strongly indicated its intention to decrease both natural gas and petroleum exports.

With Mideast nations possessing around 50% of the world's proven petroleum resources, there is reason to assume that they also possess a significant share of natural gas reserves. Regardless of the potential availability of large quantities of natural gas, the difficulties in transporting a low-density, large-volume material are many.

Most of the problems can be overcome by converting the gas into a liquid at approximately -161°C. Converting natural gas into a liquid reduces the volume of the gas by a ratio of 600 to 1, thus making it possible to store and

Table 8-1

Estimated Total Domestic Proven
Natural Gas Reserves, January 1, 1974

Location	Total Reserve (trillions of cubic feet)	Percent of Total
Texas*	84.9	34.0
Louisiana*	69.2	27.7
Alaska	31.6	12.7
Oklahoma	14.1	5.6
New Mexico	12.5	5.0
Kansas	11.7	4.7
California*	5.2	2.1
Wyoming	4.1	1.6
Other states	16.7	6.7
Total	250.0	100.0

*Includes offshore reserves.

Data from Oil and Gas Journal, vol. 72, no. 13 (April 1, 1974): 42.

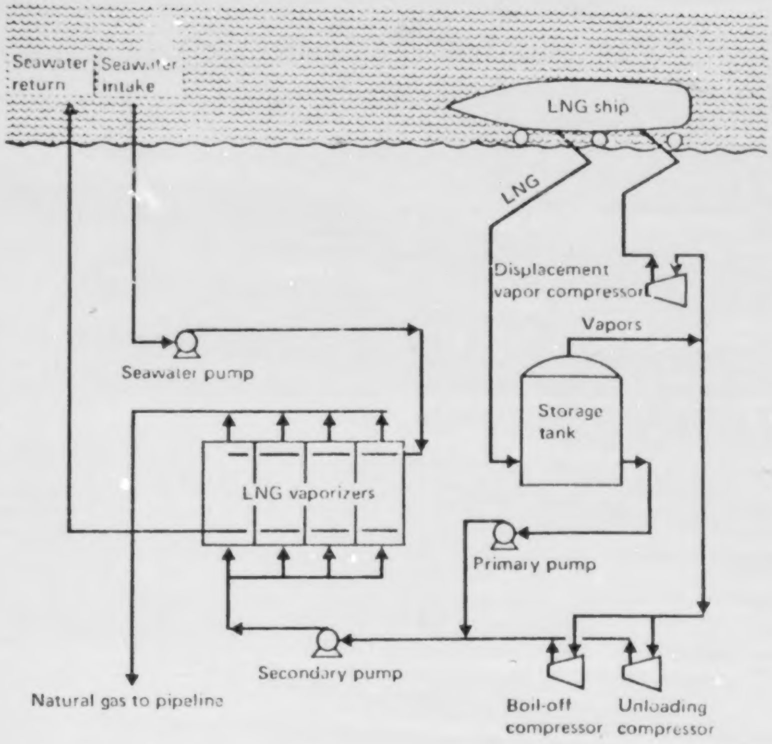
transport the gas to distant markets. Use of liquefied natural gas involves, in addition to liquefaction, such activities as transport in refrigerated tankers (at nearly $100 million apiece), regasification near the area of use (see Figure 8-2), long-term agreements between participating countries and the likelihood of environmental confrontations. Development of agreements which can weather international politics and strife may be the most difficult of the numerous "challenges" awaiting LNG proponents.

For the U.S., at least, many of the difficulties in securing adequate supplies of natural gas are due in large measure to an attitude of indifference, an attitude created in large part by court action which set natural gas prices at abnormally and unnecessarily low levels over the years. We should at all costs avoid repeating a federal policy which controlled the sale of natural gas at a price which rewarded the natural gas producer about one-third as handsomely as the crude oil producer for comparable energy yields. (Table 8-2)

From about 1966 on, the federally regulated wellhead price for domestic natural gas was less than the cost of production. Consequences of this ill-advised government action have been far-reaching, and at least four dubious results have occurred. (See Table 8-3)

1. Exploration and development by petroleum and natural gas companies has decreased sharply.
2. Demand has been enormously stimulated, with the consequence that utilities and industries have switched in large numbers from oil and coal to natural gas.
3. Reserves have diminished.
4. Interstate exports have dropped.

Figure 8-2


Seawater return
Seawater intake
LNG ship
LNG
Displacement vapor compressor
Vapors
Seawater pump
Storage tank
LNG vaporizers
Primary pump
Secondary pump
Natural gas to pipeline
Boil-off compressor
Unloading compressor

LNG Regasification Facility

Reprinted with permission from The Petroleum Publishing Company from "Design needs for base-load LNG storage, regasification" by Robert N. DiNapoli, *Oil and Gas Journal,* vol. 71, no. 43 (Oct. 22, 1973): Fig. 1, p. 67.

Table 8-2

Costs For Alternative Gas Sources* (dollars per 1000 cubic feet)

	Future price range (1973-80)
Natural gas - associated	0.35-0.95
Natural gas - nonassociated	0.35-0.95
Natural gas - stimulated	0.70-1.50
Synthetic gas - oil or naphtha †	1.00-1.70
Synthetic gas - coal	0.90-1.95
Pipeline gas - from Alaska	1.00-1.35
Pipeline gas - from Canadian Arctic	1.00-1.50
Liquefied natural gas from Alaska**	1.50-2.18
Liquefied natural gas from Canada, Venezuela††	1.00-2.20
Liquefied natural gas from Eastern Hemisphere	1.00-1.89

*Based on estimates from 7 reporting companies with differing variables.

†Assuming feedstock not exceeding 10 cents per gallon.

**To west coast, United States

††Cost varies from Canada and Venezuela, and also depends on point of entry to the United States.

Reprinted from "Fuel and Energy Resources, 1972," Part 2, U.S. House of Representatives Subcommittee Hearings, April 1972, Appendix B, p. 543.

Table 8-3

Natural Gas Price Trend

	Cost per Thousand Cubic Feet			Cost per Thousand Cubic Feet	
	Current ¢	Constant ¢*		Current ¢	Constant ¢
1956	10.8	13.3	1966	15.7	16.2
1957	11.3	13.4	1967	16.0	16.0
1958	11.9	13.8	1968	16.4	15.7
1959	12.9	14.8	1969	16.7	15.2
1960	14.0	15.8	1970	17.1	14.7
1961	15.1	16.9	1971	18.2	15.0
1962	15.5	17.1	1972	18.6	-
1963	15.8	17.2	1973	21.3	-
1964	15.4	16.6			
1965	15.6	16.5			

*1967 is used as the base year.

Data selected from "Trends in Oil and Gas Exploration," Part 2, U.S. Senate subcommittee Hearings, Aug. 1972, p. 986.

Latest data foreshadow a continuing decline in natural gas supplies. On that assumption, let's examine some of the proposals for extention of domestic natural gas supplies and for substitution of other gaseous fuels for natural gas.

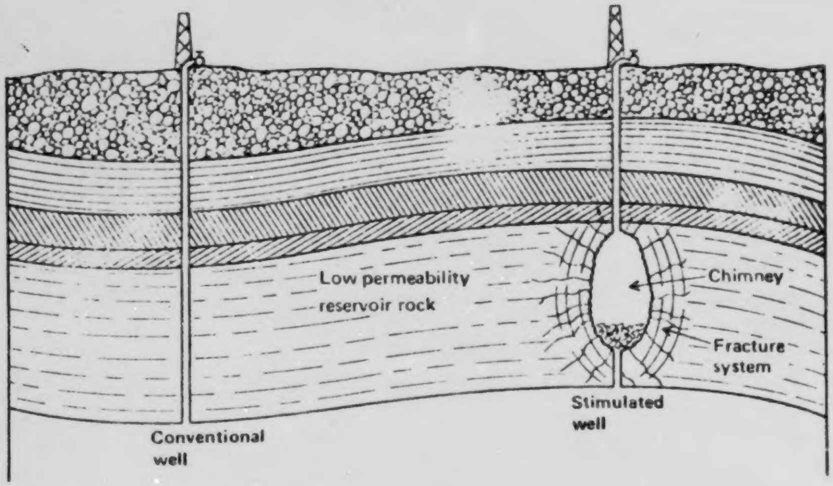
Project Gas Buggy, the U.S. Energy Research and Development Administration effort to accelerate the flow of natural gas in strata of low permeability, has received wide attention. (See Figure 8-3)

The U.S. Bureau of Mines has estimated that volumes of natural gas locked in low-permeability formations in Wyoming, Utah, Colorado and New Mexico exceed existing proved natural gas reserves. Since traditional procedures to extract the gas have failed, effort has been made to develop new methods to tap rocks of low permeability.

With usual extraction procedures precluded by the vast acreages and drilling depths involved, the research project was designed to test the feasibility of using nuclear devices to stimulate tightly packed natural gas formations. The first and second tests involved detonation of relatively small charges underground. The third test involved the simultaneously detonation of three explosives in a single well at varying depths. Other experiments using larger devices and difference placement procedures are planned.

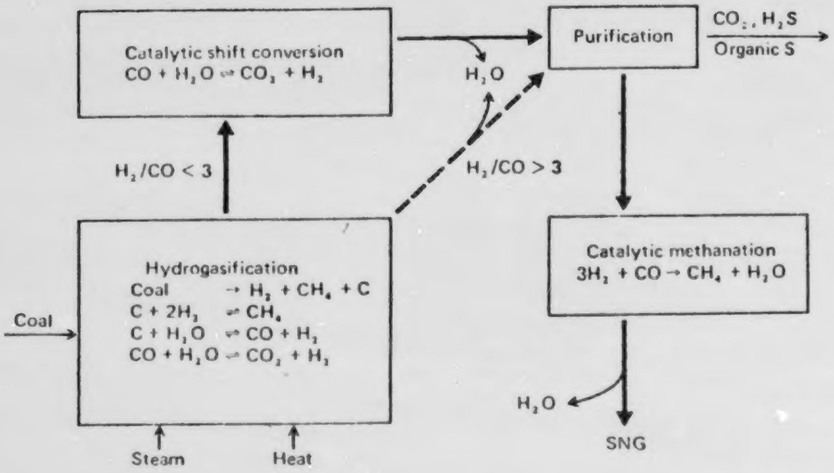
Results indicate clearly that stimulation techniques are successful; however, two undesirable side-effects result. Seismic waves result from the nuclear detonations, and there is residual radioactivity. The effects of the seismic waves have now been demonstrated to be local. Study of the radioisotopes associated with nuclear stimulation show that after a few months, tritium, krypton 85 and carbon 14 remain in significant quantities.

Figure 8-3


Low permeability
reservoir rock
Chimney
Fracture
system
Stimulated
well
Conventional
well

Nuclear Stimulation of Low-Permeability Gas Reservoirs

Figure 8-4


Catalytic shift conversion
$CO + H_2O \rightleftharpoons CO_2 + H_2$
H_2O
Purification
CO_2, H_2S
Organic S
$H_2/CO < 3$
$H_2/CO > 3$
Hydrogasification
$Coal \rightarrow H_2 + CH_4 + C$
$C + 2H_2 \rightleftharpoons CH_4$
$C + H_2O \rightleftharpoons CO + H_2$
$CO + H_2O \rightleftharpoons CO_2 + H_2$
Coal
Steam
Heat
Catalytic methanation
$3H_2 + CO \rightarrow CH_4 + H_2O$
H_2O
SNG

A Generalized Flow Chart for Coal Gasification

Redrawn with permission from "Gasification: A Rediscovered Source of Clean Fuel," by Thomas H. Maugh, II, in *Science*, vol. 178 (Oct. 6, 1972): Fig. 1, p. 45. Copyright 1972 by the American Association for the Advancement of Science.

Possible hazards are avoided by leaving the "chimney" or cavity produced by the explosion intact until the isotopes have decayed through natural processes. While the data suggest that radiation is at acceptably low levels, additional research may call for storing the natural gas for longer periods.

Coal Gasification

Coal is the world's most abundant fossil fuel, with the major part of the global coal reserves held by the U.S., USSR and China. Coal supplies less than 20% of the overall U.S. energy demand. Inexpensive natural gas and the extensive environmental impacts of coal mining and coal burning have worked to slow the nation's utilization of coal.

Conversion of coal into synthetic natural gas (SNG) is under intensive study. Our nationwide pipeline distribution system, designed for the movement of large quantities of natural gas under pressure, could be easily adapted for SNG from coal.

As desirable as that option appears on the surface, difficulties do exist. Conversion of solid coal into SNG eats up about 25% of the energy in the transformation process, although existing technologies can produce SNG which approaches natural gas in Btu value. This is accomplished through methanation, a process which adds to the cost of the final product. (See Figure 8-4)

A third, and possibly most compelling, reason for proceeding slowly with large-scale coal gasification programs is that there is evidence to suggest that gasification is less efficient than direct use of coal in many applications. If this is true, large-scale gasification could wastefully deplete coal supplies.

Encouragingly, SNG can be produced from materials other than coal. In fact, a number of modern plants in the U.S. are designed to produce SNG from naptha, a petroleum feedstock. The conversion process involves the transformation of the feedstock (naptha) into a mixture of gases, primarily methane. Continued treatment under pressure and high temperature transforms such additional materials in the mixture as carbon dioxide and carbon monoxide into methane.

The final product is essentially pure methane with an energy content approximately the same as that of commercial natural gas, 1,000 to 1,050 Btu/ft.^{3}. Supplies of naptha, the primary SNG feedstock, have to date been imported from Canada. However, the Caribbean, Europe and, ultimately, the Mideast may serve to provide an increasingly stable source of the materials from which SNG can be produced.

CHAPTER 9

COAL

Man's introduction to coal came about through accidental discovery that this hard black material supported combustion more favorably than other materials. The first extractive efforts were in deposits at or near the surface; mining of subsurface deposits came about only as a matter of necessity. Surface, or strip, mining was introduced about 50 years ago and has reached its present stage largely through the development of mammoth earth removal and material handling equipment.

Most Californians are unaware that coal has in times past contributed significantly to the energy needs of their state. Not far from the 350,000 acres of peat soils in the Delta of the Sacramento and San Joaquin Rivers may be found the remnants of the Black Diamond Mines, a coal operation dating back to the Civil War. Despite an expenditure of $150,000, an astronomical sum in 1865, the mine produced only 30,000 tons of coal. The East Bay Regional Park District hopes to develop a park at the old site.

A few years ago the Ford Motor Company introduced the motto, "There's a Ford in Your Future." Today, we might legitimately plagiarize that motto and alter it to read, "There's coal in your energy future." Coal now ranks third behind petroleum and natural gas as a contributor to meeting the energy needs of the United States. But, whereas both petroleum and natural gas have predictably short energy futures, the future for coal is far brighter.

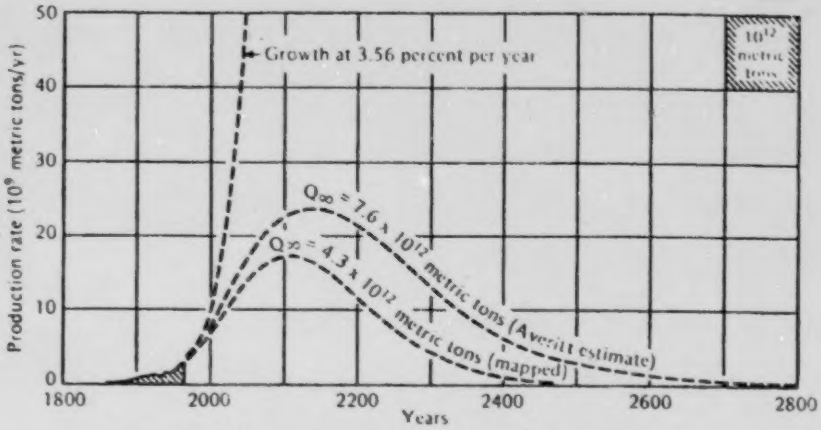
Coal accounts for 93% of the global supply of fossil fuels and 80% of the U.S. fossil fuel supply. It "fueled" the industrial revolution, both abroad and in the U.S., and provided approximately 80% of the world's primary energy up to 1920. Since 1920, the role of coal in meeting primary energy needs has declined sharply. About 20% of U.S. energy needs are now provided by coal, about 25% on a global scale.

Why is coal, with many unsatisfactory characteristics, today enjoying a massive resurgence of interest? The answer is that coal constitutes the only fossil fuel available in large quantities. Despite its many use-related deficiencies, coal has no realistic fossil fuel rivals. A significant portion of our primary energy needs must be achieved via the utilization of coal.

With world reserves of recoverable coal estimated to exceed 5 trillion tons, with annual world energy demand increasing at a rate of 4% to 5% per year, and with a much higher annual worldwide rate of increase in the consumption of electricity, there is no immediately available primary energy form to substitute for the declining availability of petroleum and natural gas. The use of coal by U.S. electric power utilities has increased constantly since the early 1930's. Utilities now consume some 70% of all coal produced. All other industries show a decline in usage, with railroads demonstrating an almost vertical reduction in use.

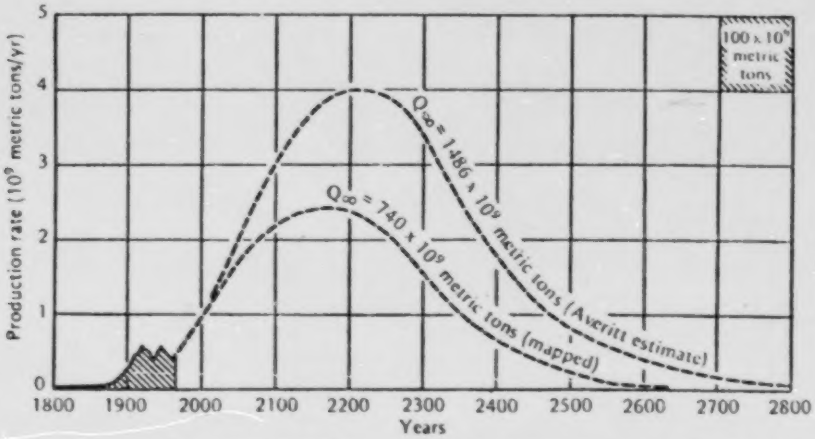
Large-scale use of coal in Europe during the 17th and 18th Centuries had less to do with the fuels virtues than with the fact that there was no other realistic energy option. Coal catalyzed the development of heavy industry, both in Europe and the U.S., and managed to maintain its role as the primary energy source until the early 1900's. (See Figures 9-1 and 9-2)

Figure 9-1



.Complete cycle of world coal production for two values of Q_∞ (Hubbert, 1969, Figure 8.25).

Figure 9-2



Complete cycle of United States coal production for two values of Q_∞ (Hubbert, 1969, Figure 8.26).

Review of early industrial history in Europe and the U.S. demonstrates clearly that during that period, coal-produced pollutant emissions were both a nuisance and an unrecognized human health hazard. With the arrival of petroleum and, later, natural gas, coal went into decline. Its revival will depend in large measure on improved methods for extraction, transportation, handling, and controlling the products of combustion.

All fossil fuels are derivations of plant and animal life. In the case of plants, 16 specific chemical elements are required for growth and maturation. The major substances used by plants are: carbon, hydrogen, oxygen, nitrogen, phosphorous and sulphur. Of those nutrients, only carbon and oxygen are of significant interest to combustion engineers. Unfortunately, the remaining elements, constituting essential components of plant and animal tissues, persist in varying quantities in fossil fuels.

Of the materials other than carbon and hydrogen, sulphur is the most troublesome and is a particular problem when it is present in airborne concentrations. Sulphur content varies in fossil fuels, because the relatively fixed amounts of sulphur present during the growth period are subjected to an immensely varied environment during decomposition and transformation.

If organic materials are exposed to high levels of sulphur, they inevitably reflect increased percentages of combined and associated sulphur forms. Removal of the chemically combined sulphur, either before or after combustion, involves difficult and expensive techniques.

The typical coal mined in the U.S. contains about 2.5% sulphur by weight, some 50% of which is in the form of pyrites, or inorganic sulphur, with the remainder in chemically bound forms, i.e., organic sulphur. With few exceptions, most of the U.S. coal deposits containing ±1% total sulphur are located in the Rocky Mountain states.

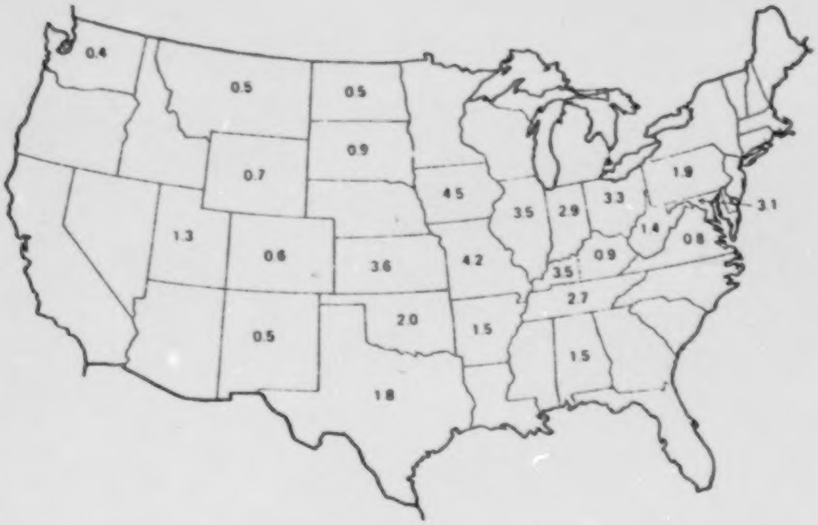
The poorest grade of coal, called lignite, represents the initial stage in the carbonization process and is believed to be of relatively recent origin, something less that 70 million years of age. Lignite possesses much of the remnants of the original organic materials, is low in Btu value and tends to dry quickly and to crumble. This latter characteristic make lignites difficult to transport.

Next in the scale of development is bituminous coal, which contains appreciably larger percentages of carbon than lignite and is thought to come from deposits approximately 70 to 300 million years of age. The most desirable coal in terms of Btu value is anthracite which represents the final stage in the coal transformation process. Because of its high percentage of carbon (92+), anthracite coal is very hard and easily fractured. Its high carbon content produces combustion with a bright, soot-free flame. (See Figure 9-3)

Coal - Distribution, Deposits and Reserves

The Asian continent possesses some 50% of the world's coal resources, most of which are in the USSR and China. The North American continent, i.e., the U.S. and Canada, has about one-third of the world's coal, while Europe (13%) and the continents of Australia, Africa and South America share the remainder.

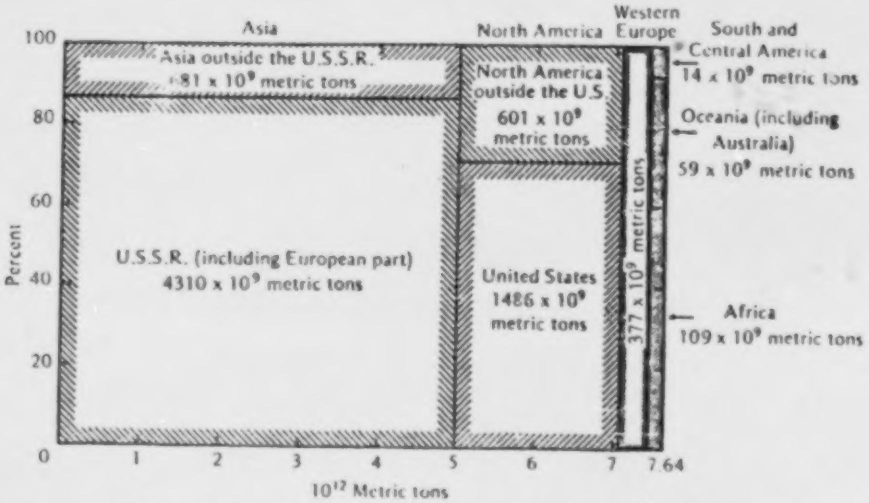
Figure 9-3


0.4
0.5
0.5
0.9
0.7
4.5
3.5
2.9
3.3
1.9
3.1
1.3
0.6
3.6
4.2
1.4
0.8
0.9
3.5
2.7
2.0
1.5
0.5
1.5
1.8

Average Sulfur Content of Coal Deposits in the Conterminous United States (Percent)

From "Average Sulfur Content of U.S. Coal Deposits," J. Calvin Giddings, *Chemistry, Man and Environmental Change* (New York: Harper & Row, 1973), Fig. 7–12, p. 262.

Figure 9-4



Averitt (1969) estimate of original world recoverable coal resources (Hubbert, 1969, Figure 8.24).

Figure 9-4 shows that the world's recoverable coal reserves are approximately 2,400 (10^9) metric tons. For the U.S., the figure is 780 (10^9). Man's one-thousand-year coal mining efforts have produced about *99 (10^9) metric* tons. U.S. production comes to roughly 32 (10^9) metric tons. (See Table 9-1)

Of the U.S. coal resources believed to exist, a significant portion is either not recoverable by known or projected technologies, or it may consist of such low-grade coals that no net energy yield is possible. Overall, less than one-third of the estimated U.S. reserves may be available for beneficial use. If this is accurate, projections of the long-term ability of coal to meet increasing energy needs may well be more optimistic than realistic.

Determination of the life index ratio for U.S. coal may be made by comparing annual U.S. production in millions of tons (600) to the total recoverable reserves available in the U.S. This yields a life index ratio of about 870 to 1. However, if the ratio is computed on the basis of the bituminous reserves alone, which constitute 98% of current use, the result is a much lower 593 to 1. Lignite is being used increasingly.

Underground mining, which until recent years provided the major portion of the coal available to industry, now supplies about 50% of U.S. coal needs. Unfortunately, underground mining is wasteful of coal resources. Conventional room-and-pillar mining leaves as much as 50% of the coal in place to support the weight of rock above the coal seam. The long wall mining method now recovers up to 80%.

Table 9-1

Recoverable Coal Reserves In The United States, Dec. 31, 1970

Coal Rank	Estimated Reserves (billions of tons)	Estimated Recoverable Reserves (billions of tons)	Estimated % Recoverable
Lignite	447	179	40.0
Bituminous	1113	360	32.3
Anthracite	16	3	18.8
Total	1576	542	34.4

Data from "United States Coal Resources and Production," U.S. Dept. of the Interior, Bureau of Mines, June 1971, pp. 3, 9, 10.

Even under the best conditions, underground mines are dangerous environments. In 1975, 154 deaths occurred in underground mines. Passage of the Coal Mine Health and Safety Act of 1969 has both improved safety programs and increased the cost of operations. One consequence of the legislation, regardless of its desirability, may be to accelerate the trend toward surface mining to the point that surface mining, despite its environmental disadvantages, becomes the dominant method for extracting coal.

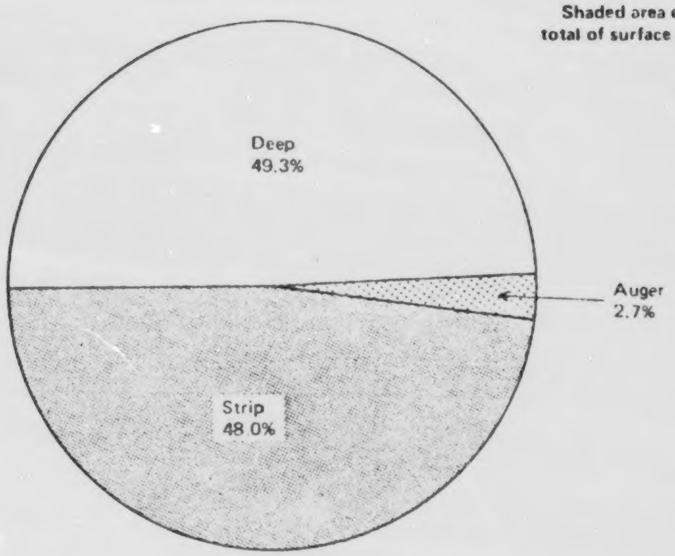
From a resource sense, surface mining offers many advantages. Nearly 90% of the coal in surface seams can be extracted, making the operation almost twice as efficient as underground mining. The increased production of coal by surface mining results primarily from the development of massive excavating equipment within the last 10 to 15 years. Some of the larger electrically powered drag lines possess bucket capabilities exceeding 200 cubic yards.

In the last decade, production per manhour has nearly doubled in surface mining. A second consequence of large-scale earth moving equipment is that operators are now able to remove greater thicknesses of overburden (25 feet more between 1946 and 1970). It appears possible that 15 or 20 years from now machinery may be developed which will permit removal of 300 feet of overburden. (See Figures 9-5 and 9-6)

Use Related Problems

Proposals to utilize the large quantities of coal in the U.S. and other parts of the world must recognize that significant environmental costs are involved. Although the negative environmental effects of coal use are recognized universally, most countries have less well-developed environmental protection programs than does the U.S.

Figure 9-5

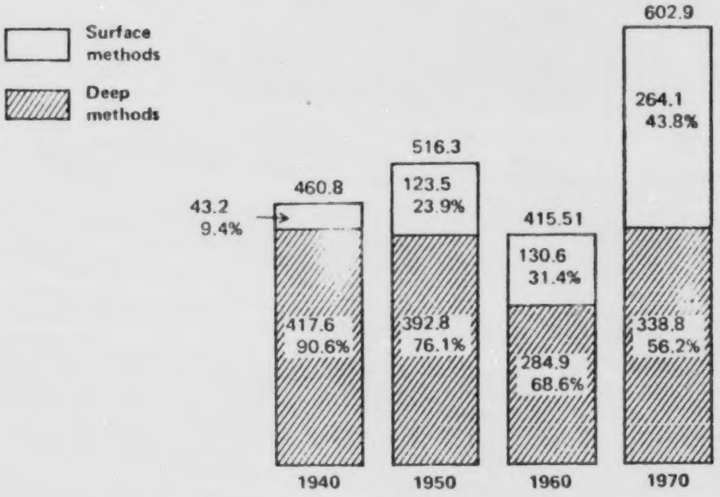


Shaded area equals total of surface methods

Percent of U.S. Bituminous and Lignite Coal Produced by Various Mining Methods, 1973

Data from *Coal Age* (Feb. 1974): 84. Reprinted by permission of McGraw-Hill, Inc.

Figure 9-6



United States Production of Bituminous and Lignite Coal at Deep and Surface Mines, 1940–70 (Millions of tons and percent of total given)

Data from "Relationship of Energy and Fuel Shortages to the Nation's Internal Development," U.S. House of Representatives Subcommittee Hearings, Aug. 1972, p. 949.

The direct and obvious effect of surface mining is steep, nearly vertical, piles of spoil top soil material stacked along the down slope side of the excavation. Traditionally, top soil, one of the important components of our life support system, has been incorporated into the spoil material with essentially no chance of recovery.

The environmental effects of strip mining have not been confined just to the area from which the coal was removed. In many coal mining regions of the East, extreme siltation, accelerated because of loose material and steep slopes, extends the effect of the mining far beyond the removal site.

Studies by the Appalachian Regional Commission demonstrate that degradation of water quality in the major streams of the Appalachian area has resulted through the addition of suspended materials and through the introduction of acid water from the oxidation of pyrites in the major percentage of coal deposits. However, use of western coal deposits, located in different climatic regimes, may be accomplished with less environmental impact.

Significant advances have been made in restoring areas where coal has been extracted. Additional research and improvements in technology are indicated if our need for coal is not to seriously damage other vital ecosystems.

Without vigilant attention to environmental quality, mining in areas of poor coal could result in reclamation programs inferior to those in areas of higher quality coal. Standards need not be uniform, but they should achieve some reasonable restoration of the original environmental condition of the area and anticipate possible future uses. Based on existing programs, at least two reclamation levels appear desirable.

1. Complete reclamation would include the return of the land as nearly as possible to its original surface configuration, employing revegetation with native plant types or the introduction of species which appear environmentally more responsive to the original cover. Data developed by the Appalachian Regional Commission indicate that return of the area to its original state, including the covering of the spoils area with top soil, conditioning the soil with mulches and fertilizers, and revegetating can vary from $1,500 to $4,000 per acre.
2. Partial reclamation involves leaving the surface in a configuration which permits the area to become productive within a reasonable period after mining. The placement of original top soil or an acceptable substitute is required, but restoration of the vegetation requires only that the spoil material be placed in a configuration which minimizes landslides or accelerated levels of erosion. The construction of catch basins to serve as settling ponds for eroded material and basic revegetation designed to assist in erosion control are required.

New technologies to increase rates of coal extraction have outpaced improvements in transportation techniques. Transportation costs are a major influence in plant location decisions. If industries which rely on coal for energy remain where they are as coal mining moves westward, the need to improve transportation will become even more critical.

One idea that may ease the coal transportation bottleneck is to transport coal in a coal-and-water slurry via pipeline. The technology involves pulverizing or powdering the coal at the mine-mouth, mixing it with water to produce a viscous slurry and pumping it through a pipeline to markets.

Large quantities of water are needed to produce the slurry mixture, there are relatively high corrosion losses to pumps and pipeline facilities, and water disposal facilities are required at the point of utilization. Some studies suggest that pipeline transportation can be carried out at lower unit (Btu) cost than rail transport. The extent to which the railroads attempt to meet this newest form of competition remains to be seen.

Environmental Effects of Coal Combustion

The most desirable coal, anthracite, comprises only 2% of U.S. coal reserves. Anthracites have the advantage of being clean-burning and containing extremely small amounts of sulphur. The U.S. has been particularly wasteful of anthracite. Bituminous coal is the single source of "coking" coal (coke is used in smelting iron and steel). Coking coals have been exported for use in steel production, in a number of processes where a poorer grade of coal would have sufficed.

Bituminous coal, the most widely used grade, features moderate smoke production, varying sulphur content and low moisture content. About 42% of existing U.S. reserves are bituminous, with 43% of those deposits containing more than 3% sulphur. Their use, under existing air quality regulations, would either be undesirable or illegal.

Sub-bituminous and lignite coals comprise nearly 56% of the U.S. reserves. These coals are of low quality, possess a low percentage of sulphur and fixed carbon, a high moisture content and, generally, ash percentages of from 10 to 15.

In one hour, a typical 1000-Mw coal-fired electric power plant burns 340 tons of coal and produces 17 tons of SO_x, 3.4 tons of NO_x, 34 tons of ash and 13 tons of CO. The American Public Health Association has estimated that some 3,800 more people would die annually from respiratory and cardiac-related diseases if existing electric power plants were switched from natural gas or low-sulphur oil to bituminous coal (with control on emissions).

Conversion to coal from natural gas and oil will depend on solutions which minimize, and reduce to the greatest possible extent, air quality problems associated with coal burning. Sulphur control is imperative. A number of choices exist. One is to use only low-sulphur coal, thus minimizing the production of SO_x. A second is to remove the sulphur before the combustion process, either physically or through chemical treatment. The third is the removal of sulphur after combustion.

In the first instance, the quantity of low-sulphur coal (0.5% by weight) which meets the environmental requirements for ash, Btu ratings, etc., is quite limited. It thus appears that the real choices remaining involve the removal of sulphur either from the combustion products or from the coal before burning. In either case, removal will be costly and must ultimately be borne by the consumer.

In addition to sulphur removal methods already noted, a new process, coal desulphurization, is under development. This involves removal of the sulphur through the use of an iron catalyst which converts the inorganic sulphur pyrites into elemental sulphur and sulfate. The iron compounds might then be stored in excavated areas to offset problems associated with mine subsidence. No doubt, as research in sulphur removal accelerates, other processes will be developed.

Conversion Technologies - Alternatives to Solid Coal

"Coal gasification" describes the transformation of solid coal into a gas which approaches the virtues of natural gas. Pipeline quality natural gas is virtually all methane, is essentially sulphur-free and averages 1,080 Btu per ft.^{3}.

Gas from coal is primarily methane, is essentially free of sulphur, contains very little of the gases which do not contribute to the combustion process and averages about 1,000 Btu per ft.^{3}. Coal-to-gas conversion involves the reaction of carbon in coal with hydrogen to form methane. The usual source of hydrogen is hydrogen gas.

A number of different coal gasification processes are being developed, but all use basically the same chemical reactions. While the sequence may vary, the typical process involves grinding the coal to a powder, preheating that material with air or oxygen to minimize caking, and then heating to 1,500°C at pressures up to 70 atmospheres (one atmosphere equals 14.9 pounds).

Researchers are attempting to realize in situ (underground) coal gasification which eliminates the need for mining, retorting and handling waste materials. One of the concepts introduced by the Lawrence Livermore Laboratory involves the gasification of deep coal deposits through the use of chemical high explosives to break up the coal-bearing formations. The explosion produces a large rubble zone which is then ignited and burned by a steam-oxygen mixture. Methane and other gases are produced. Brought to the surface, these gases are converted to high quality gas that can then be transported through the existing network of gas pipelines.

In situ gasification, in theory, can reduce surface waste, lower capital investment and significantly reduce operating costs common to surface gasification plants. The Lawrence Livermore Laboratory estimates that if 30% of deep-lying western coal could be processed in situ, potential reserves of natural gas would climb to 30 times present reserves. LLL researchers believe that the technology can become commercially feasible by 1985.

Coal gasification utilizes the products of incomplete combustion. After ignition, the amount of oxygen made available to the material being gasified is reduced. When a temperature of approximately 1,500°C is achieved, steam is injected into the system where it reacts with both the carbon and carbon monoxide which are present.

Both carbon monoxide and hydrogen can be burned to produce energy. Methane is the third ingredient of the material produced. Through additional processing, the chemical composition of the gas is altered and the final Btu of the material exceeds 1,000 Btu per/ft.^{3}.

Coal can also be liquefied to produce a synthetic petroleum. One of the U.S. processes that has reached an advanced stage is the COED process. (Char Oil-Energy-Development process). In the COED technique, the crushed coal is heated to increasingly higher temperatures in a series of reactors. At each stage a part of the volatile matter in the coal is removed. Heat for the process is provided by burning the residual char and, in effect, utilizing an unwanted byproduct to energize the process.

The materials produced from the heating process are cooled and condensed, and, after further processing to insure purity, they can be used as a substitute for liquid petroleum. (Despite efforts to develop technologies which will permit the production of high-quality lubricants from coal, that objective has not yet been achieved. At this time it appears that for all practical purposes, coal is not likely to be a future source of high-quality lubricants.)

The principal sources of energy for the world today are the fossil fuels. They are finite and subject to all the laws that govern finite resources. At present, fossil fuels are available in sizeable quantities and are located in many different parts of the globe. Although unevenly distributed among the various nations, ample supplies would appear to exist if reasonable efforts toward intelligent use were made.

Some existing environmental regulations and much pending legislation regarding the environmental effects of coal and other fossil fuels are viewed by experienced petroleum and utility experts as excessive, uninformed, costly and counter-productive. The coal outlook may be brighter than the immediate stalemate implies if we can decrease the occupational and environmental hazards of mining.

Coal's possibilities as a raw material seem limited mainly by man's ingenuity. Long after the last oil and gas wells have declined, liquefaction and gasification of coal may provide products for which we now look to petroleum. Coal will be the raw material for an ever more diverse petro-chemical industry, and through microbiological and industrial processes, it may be converted to food.

In view of these possibilities, it seems very strange that the major portion of federal funds for energy research (86% in fiscal year 1970) is devoted to nuclear fission and fusion, while coal scrambles with a host of other contenders for its share of the balance.

The motto of the State of California is "Bring me men to match my mountains." Coal offers somewhat the same kind of challenge. Coal is versatile, it is abundant and, on the basis of research efforts thus far, it seems amenable to a large variety of uses. While coal may not be perfect, its deficiencies can be overcome to allow this useful, highly versatile fuel to contribute prominently toward the energy needs of this country for a long time to come.

6

CHAPTER 10

FROM ATOMS TO ELECTRICITY

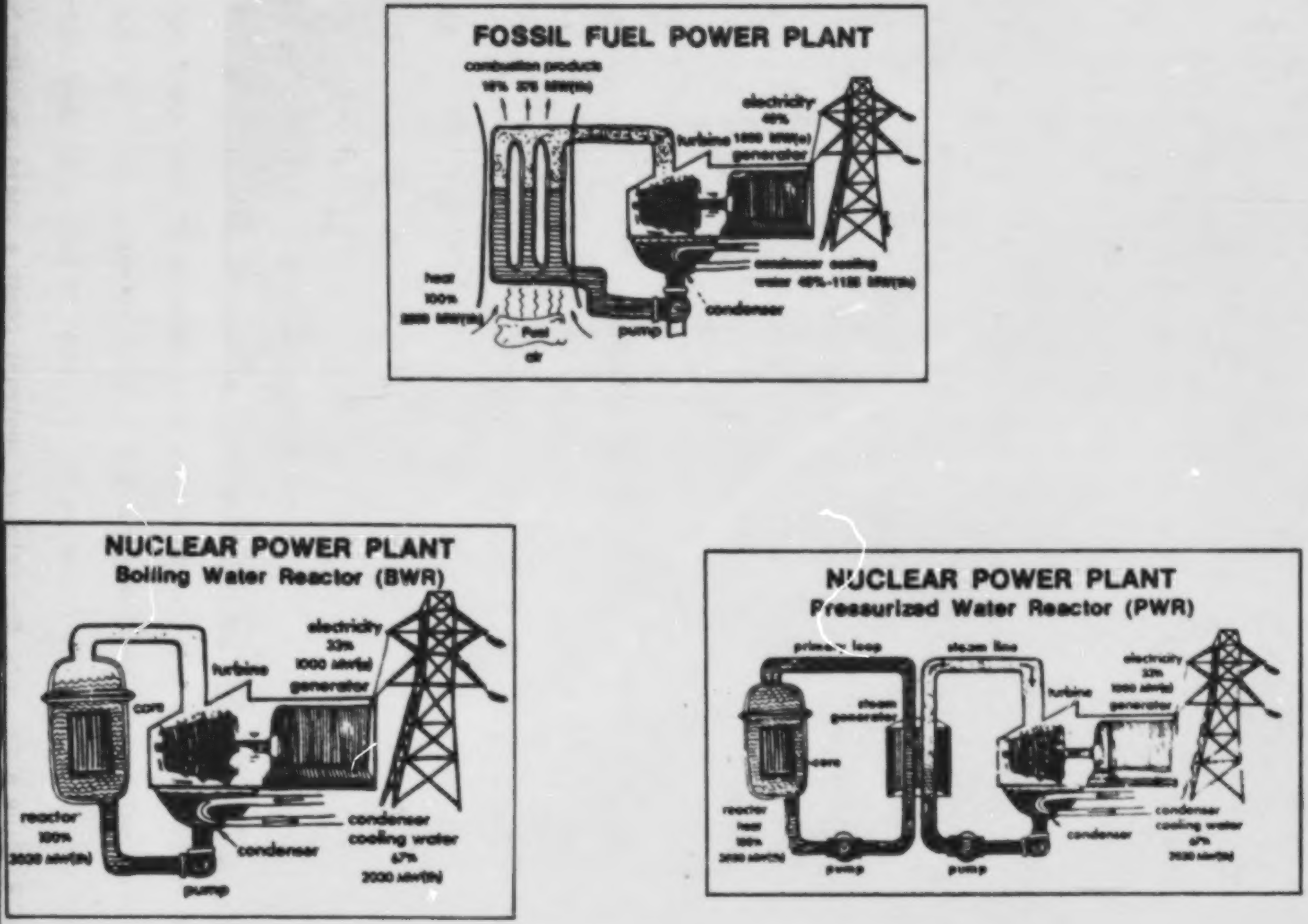
A nuclear power plant is similar to a conventional thermal power plant. Each uses steam to drive a turbine-generator that produces electricity. The heat energy of the steam is converted to mechanical energy and then into electricity. Although the turbine functions equally well no matter where the steam comes from, the origin of the steam is important; for it is here that nuclear and conventional plants differ. (See Figure 10-1)

How is steam produced? Conventional plants burn coal, oil or gas and use the heat from the combustion to convert water to steam. In nuclear plants, no burning or combustion occurs in the usual sense. Nuclear fission is used to generate heat. Heat from the fission reaction is transferred (sometimes indirectly) to the water that produces the steam. Consequently, it can be said that fission reactions in a nuclear plant serve the same purpose - the generation of heat - as the burning of fossil fuels in a conventional plant.

The fission process requires a particular kind of heavy element, such as uranium or plutonium, as a basic material. Let us consider uranium which consists of a mixture of free isotopes, atomic forms that are chemically alike, but vary in mass. An atom of one of these isotopes Uranium 235, can readily undergo fission when a free neutron strikes the nucleus.

The nucleus breaks into two particles that separate at high speed and, in addition, release two or three neutrons as well as radiation. The kinetic energy of the flying fission fragments is converted to heat when they collide with surrounding atoms, and the released neutrons cause a chain reaction by initiating new fissions with other U235 atoms.

Figure 10-1


FOSSIL FUEL POWER PLANT
combustion products
15% 375 MW(th)
electricity
40%
turbine 1000 MW(e)
generator
condenser cooling
water 45%-1125 MW(th)
heat
100%
2500 MW(th)
fuel
air
pump
condenser
NUCLEAR POWER PLANT
Boiling Water Reactor (BWR)
electricity
33%
1000 MW(e)
turbine
generator
core
reactor
100%
3000 MW(th)
condenser
condenser
cooling water
67%
2000 MW(th)
pump
NUCLEAR POWER PLANT
Pressurized Water Reactor (PWR)
primary loop
steam line
steam
generator
core
turbine
electricity
33%
1000 MW(e)
generator
reactor
heat
100%
3000 MW(th)
condenser
condenser
cooling water
67%
2000 MW(th)
pump
pump

Sustaining the chain reaction is important because more than 30 billion fissions must occur per second to release one watt of energy. If the chain reaction is to be useful, fissions must occur at a desired and controlled rate, and the heat that is generated by the process must be removed.

The job of the nuclear reactor, then, is to provide an environment in which fission reactions can be initiated, sustained and controlled, and to make possible recovery of the resultant heat. Let's examine now the details of the processes by which fuels such as U235 are converted into electrical power for homes and industries.

Structure of the Atom

Atoms of different elements differ in mass and in size. An impression of the minuteness of atoms of hydrogen may be obtained by noting that some 250 million hydrogen atoms would have to be placed alongside one another to form a line 1" long. Heavier atoms, those with high atomic weights, are somewhat larger than hydrogen atoms. Even so, a line 1" long would still require over 100 million of the largest atoms placed side-by-side.

How do atoms of various elements differ from each other? They differ in the numbers of three kinds of particles that each contains. These particles are called electrons, protons and neutrons. The number of electrically neutral atoms is always the same as the number of protons, but the number of neutrons can be different.

The structure of the atom consists of a nucleus of protons and neutrons which is surrounded by electrons. The protons and neutrons appear to be inter-mixed within the dense heavy nucleus. The electrons surrounding the nucleus are not distributed in a random fashion but rather are moving in precise orbits referred to as "shells." For the first five shells, whose numbers are 2, 8, 18, 32 and 50, these equations -- 2×1^2, 2×2^2, 2×3^2, 2×4^2 and 2×5^2 -- provide the answers to the number of electrons in their respective shells. (See Figure 10-2 and 10-3)

The Fission Process

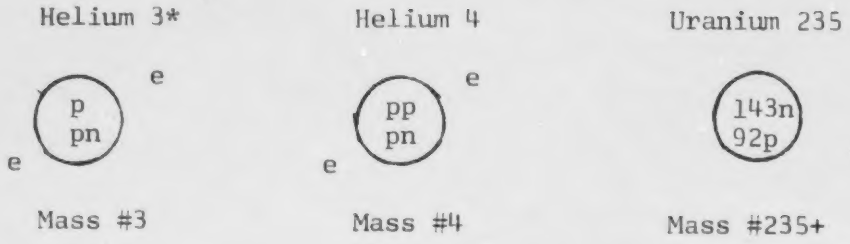
In discussing fission, it seems logical to use U235 as an example since that is the most important element used in nuclear-fueled electric generation units. Despite the publicity U235 has received, it is not the most prevalent of the uranium isotopes and is, in fact, available in relatively small quantities. By weight, the percentages of U238 are 99.28, of U235, 0.71, and of U234, 0.006.

Under special limited circumstances, atoms can release energy in a process called fission. If an isotope of a fissile element is struck by a neutron of the appropriate energy, the original large nucleus absorbs energy and subsequently breaks into smaller fragments which possess slightly less total mass than that of the original nucleus. The difference in mass appears in the form of heat which in a nuclear-fueled reactor is converted into electrical power.

Spontaneous fission occurs in all nuclei containing a total number of protons and neutrons (atomic mass) greater than 230. Since the use of spontaneous fission can occur.

Fig. 10-4 illustrates the U235 atom. An arrow shows (1) a neutron absorption and the conversion of the U235 to U236 (2) the subsequent decay (in about one one-millionth seconds) (3) the production of two or more fission fragments

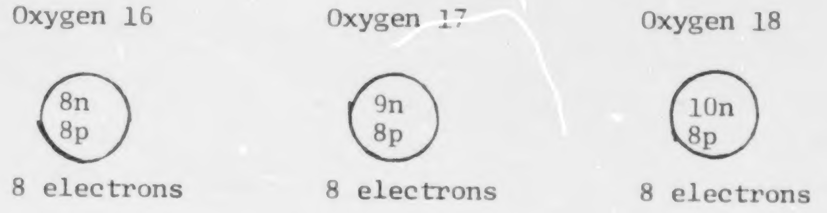
Figure 10-2


Helium 3*
Helium 4
Uranium 235
e
p
pn
e
e
pp
pn
e
143n
92p
Mass #3
Mass #4
Mass #235+

*Electron number in stable elements equals proton number.

+Uranium Isotopes have mass numbers which vary from 230 to 239. All have 92 protons but the neutron count varies from 138 to 147.

Figure 10-3

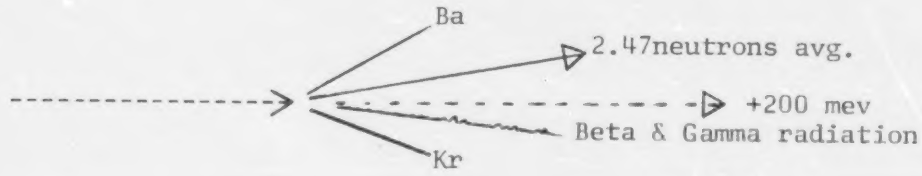

Oxygen 16
Oxygen 17
Oxygen 18
8n
8p
9n
8p
10n
8p
8 electrons
8 electrons
8 electrons

Stability decreases-----------------------------------→

Figure 10-4

$^{235}_{\ 92}U_{143} + n \dashrightarrow {}^{236}_{\ 92}U_{144}$ (elapsed time is within 1millionth of a second)

Figure 10-5


Ba
2.47neutrons avg.
+200 mev
Beta & Gamma radiation
Kr

which may consist of a number of new and different elements (4) the release of a beta particle, gamma radiation and energy. A small amount of the energy, released (12% on average) is lost through radioactive emissions and contribute nothing to the heat yield of the reactor unit.

Recall that, the average energy release from chemical reaction, i.e., the movement of an electron from one shell to another, external to the nucleus, averages 10 electron volts. The average energy release from a fission reaction is 8 million electron volts. Impressive though this energy release magnification is, the quantities are still small.

To be useful, the fission energy release process must occur many millions of times each second. A desired level of energy release and power generation is achieved by placing fissionable materials such as U235 in a compact mass so that the neutrons released from each fission are intercepted by other U235 atoms to sustain the chain reaction process.

When a uranium nucleus breaks down through natural decay processes to become a less massive lead nucleus, energy release is accompanied by a reduction in mass. When the nucleus breaks in two to become less massive nuclei, for example, barium and krypton (U→Kr+Ba), much more energy is released. A single neutron, if multiplied through a chain reaction, can trigger enormous energy releases. (See Figure 10-4 and 10-5)

A nuclear reactor is said to have achieved critical mass when the fission process sustains itself. Once criticality is achieved, control of the fissioning process at the desired rate becomes mandatory. A number of safeguards, both engineering and natural, preclude the possibility of uncontrolled reactions.

While the specific details of the control devices will be considered in later sections, the primary factors which preclude the possibility of uncontrolled escalations are:

1. The relatively low percentage of U235 in the reactor core.
2. The use of a moderator (treated water) which slows the neutrons and simultaneously acts as a coolant.
3. Placement and design of the fuel elements within the reactor core.
4. The design characteristics of the reactor itself.

Reactor Fuels (Fission Fuels)

Extensive misunderstanding exists concerning the estimated fuel supply available for light water reactors. The present generation of light-water reactors (LWR) is restricted to U235 fuel which, on the basis of general estimates, seems to be in adequate supply for 25 to 35 years.

However, thorium 232 and U238 are converted through neutron activation into U233 and Pu239, respectively. Supplies of Th232 and U238 are nearly limitless, but existing technologies do not permit utilization of these two fuels.

Total energy likely to be derived from fossil fuels in the U.S. amounts to about 8Q (1Q - 10^{18} Btu). Estimates of the probable energy available from thorium and uranium from domestic U.S. supplies is about 900Q. As far as nuclear fuels are concerned we are dependent on three sources: U235, an easily fissionable fuel; Th232 and U238. Although existing reactors can produce rather small amounts of fissionable material from Th232 and U238, large-scale power generation is dependent upon improved technologies.

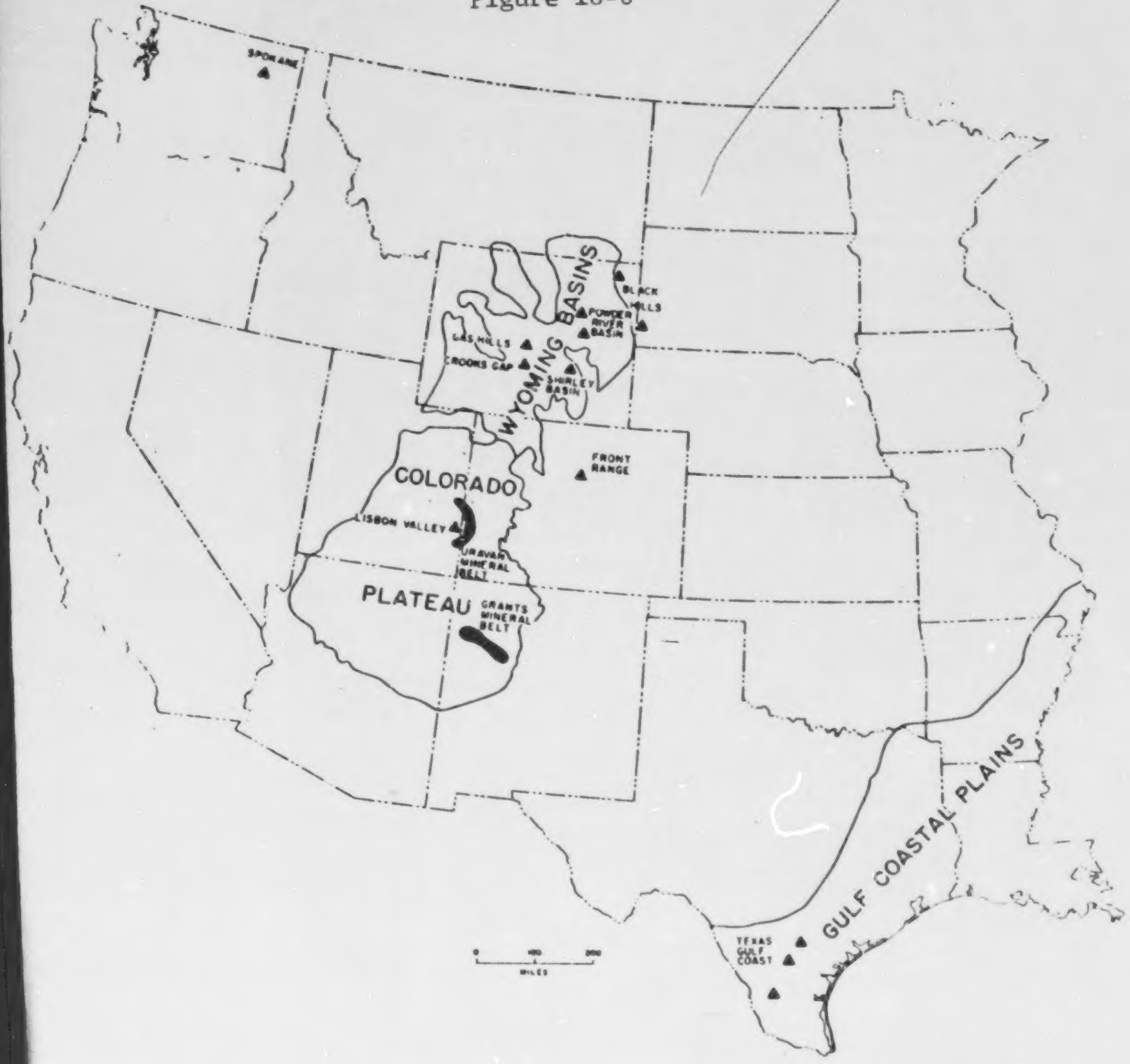
Let's examine next the geographical areas of the U.S. and of the world where significant deposits of uranium exist. Uranium makes up about two parts per million of the earth's crust, and traces of it are found almost everywhere. Its abundance is greater than that of gold, silver or mercury. There is an average of 1 pound of uranium in every 500,000 pounds of the earth's rocks. Thorium, approximately 12 parts per million, is six times as plentiful. Uranium, like most other metallic elements, does not occur in nature as a free metal. It is always found combined chemically with oxygen and other elements and usually occurs as uranium oxide, a form which provides approximately 95% of the uranium mined in the U.S.

Uranium ores are concentrated in two major sections of the U.S. The largest is the Colorado Plateau which covers parts of Colorado, Utah, Arizona and New Mexico -- an area of approximately 14,000 square miles. Uranium deposits in this region constitute the primary domestic source of the metal. The second largest region of uranium deposits is in the basins of central and northeastern Wyoming. About 90% of U.S. uranium production comes from these two western areas, with smaller contributions from the Black Hills of South Dakota, Fremont County, Colorado, and the Texas Gulf Coastal Plain. (See Figure 10-6 and Table 10-1)

Considering the future role of uranium in energy production, it should be kept in mind that while large deposits have been discovered, many parts of these uranium belts have yet to be explored. Moreover, uranium geology is still not completely understood.

Thorium, a strong nuclear fuel candidate for the future, exists in large quantities in the northeastern section of the U.S. New Hampshire deposits of Conway granite extend over an area of some 750 square kilometers and contain

Figure 10-6


SPOKANE
WYOMING BASINS
BLACK HILLS
POWDER RIVER BASIN
GAS HILLS
CROOKS GAP
SHIRLEY BASIN
FRONT RANGE
COLORADO
PLATEAU
LISBON VALLEY
URAVAN MINERAL BELT
GRANTS MINERAL BELT
GULF COASTAL PLAINS
TEXAS GULF COAST
0
100
200
MILES

PRINCIPAL URANIUM DISTRICTS OF THE UNITED STATES

Table 10-1

United States Uranium Resources,

January 1, 1974 (tons of $U_3 O_8$, cumulative)

Cost of Production ($ per pound)	Reasonably Assured (proven reserves)	Estimated Additional (potential reserves)	Total
$8 (or less)	275,000	450,000	725,000
$10 (or less)	430,000*	700,000	1,130,000
$15 (or less)	525,000*	1,000,000	1,525,000
$30 (or less)	700,000*	1,700,000	2,400,000

*Includes 90,000 tons of potentially recoverable $U_3 O_8$ as a by-product of phosphate and copper mining at a cost of $10 per pound or less.

Data from Atomic Energy Commission as published in Coal Age, April 1974, p. 80. Reprinted with permission of McGraw-Hill, Inc.

about 150 grams of thorium per cubic meter. The energy content of each cubic meter of Conway granite is equivalent roughly to 400 tons of coal or 2,000 barrels of oil.

Estimates of the energy content of a surface layer of Conway rock 100 meters thick indicate an equivalent to 100 times the world's crude oil resources or as much as 4 times that of the world's coal. Breeder reactors may be able to use thorium as fuel.

Conversion of the uranium oxide ore into fuel pellets utilized within reactor fuel rods is begun by processing the ore in a uranium mill. The ore is pulverized, and the uranium is leached with a reagent. Excess water is then removed to produce a crude uranium concentrate known as "yellowcake" which usually assays between 70% and 98% U_3O_8. While specific procedures vary, the concentrates from the uranium mills are converted to essentially pure uranium trioxide (UO_3), a very fine powder of brilliant orange hue, hence, the name orange oxide. Interestingly, long before the atomic age was born, this same material was produced for use as a coloring agent in chinaware.

The orange oxide is then converted by hydrogenenation into uranium dioxide (UO_2), which in turn is converted to uranium tetracloride (UF_4), called green salt. The green salt is then reacted with florine gas to convert it to uranium hexafluoride.

It is important to note that for use as reactor fuel, uranium must be refined to purity standards commensurate with those of the pharmaceutical industry. The reason is that impurities are "excess baggage" in a nuclear reactor. They absorb neutrons unproductively and lower the efficiency of the system.

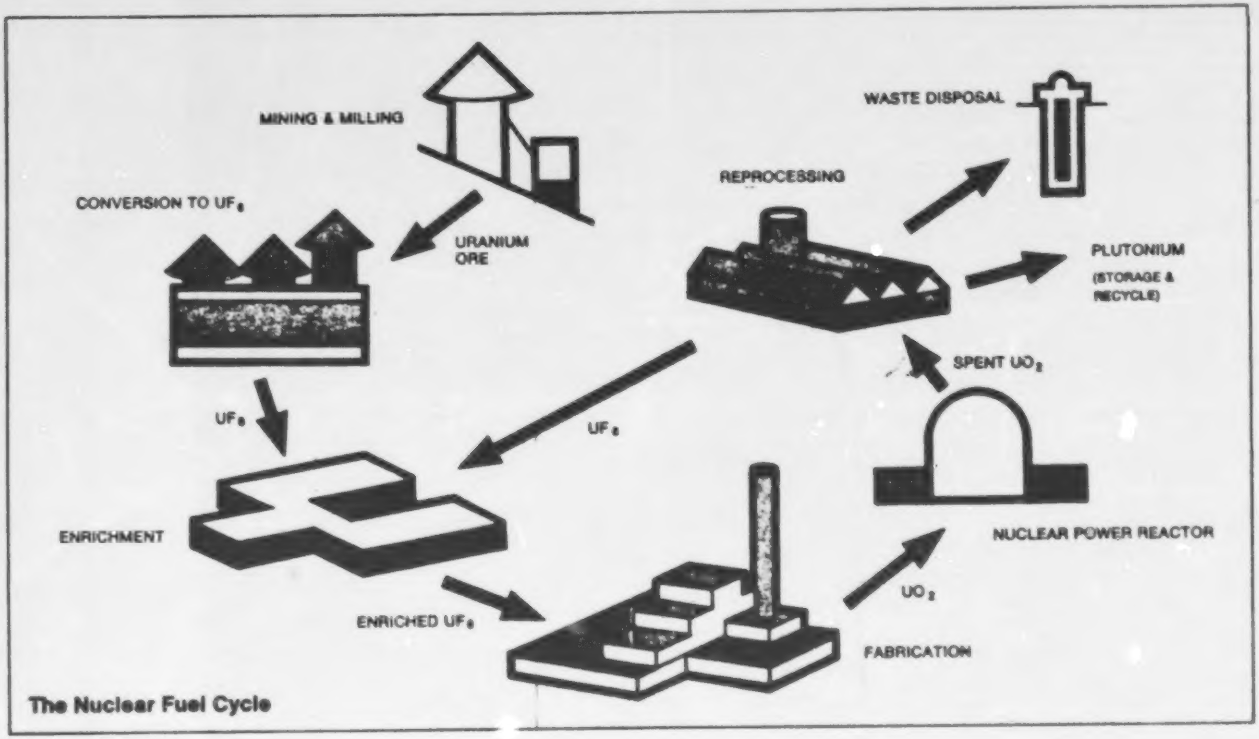
The next (one of the most difficult and important) step in the fuel refining and fabrication process involves increasing the U235 content of the fuel from a natural level of .72% to somewhere between 2.4% and 3.3%. Uranium enrichment in the U.S. is achieved through the gaseous diffusion process which is described in considerable detail in numerous texts.

Separation via gaseous diffusion is achieved through the differences in mass between 235 UF_6 and 238 UF_6. The gaseous diffusion process can be likened to filtration except that it depends on extremely slight differences in solid particle sizes and takes advantage of gas particle mobility.

The molecules of a gas are constantly in motion and dart about in random directions. 235UF_2 gas molecules travel at slightly higher velocities than the heavier 238UF_6 molecules. Advantage is taken of this fact to separate the components. Although many stages are required to accomplish significant separation of the uranium isotopes, separation is achieved to a remarkable extent.

The most recent and promising development in uranium enrichment employs a high-speed centrifuge to separate the isotopes on the basis of mass. The primary advantage of the centrifuge is a significant reduction in the energy required to produce an equivalent amount of enriched material. The centrifuge uses an estimated 10% of the energy required in gaseous diffusion. Also, under development is a laser isotope separation process which could be even more efficient. (See Figure 10-7)

Figure 10-7


MINING & MILLING
URANIUM ORE
CONVERSION TO UF_6
UF_6
ENRICHMENT
ENRICHED UF_6
FABRICATION
UO_2
NUCLEAR POWER REACTOR
SPENT UO_2
REPROCESSING
WASTE DISPOSAL
PLUTONIUM
(STORAGE & RECYCLE)
UF_6

The Nuclear Fuel Cycle

Before reactor fuel elements can be fabricated, the uranium hexafluoride must be converted to a form compatible with the intended application. The choice of fuel materials for power reactors depends on several factors. Usually the governing considerations are:

1. The ability of the material to withstand the damaging effects of irradiation.
2. The chemical and nuclear properties of the material.
3. The ease of fabrication.

Uranium dioxide (UO_2) is the material in most common use today and is the standard fuel for reactors of the pressurized and boiling water types. Other ceramic materials such as uranium carbide are being developed for use in higher temperature systems such as gas-cooled reactors. Uranium dioxide is produced by reacting uranium hexafluoride with water and then with an hydroxide salt. A precipitate results which is reduced with hydrogen to form uranium dioxide powder.

Next, compacted uranium dioxide and other binder materials are packed in small cylindrical pellets. After careful inspection, these pellets are loaded into thin-walled cladding tubes, made of an alloy of zirconium. After loading, helium is then introduced into the tube for "thermobonding" which serves to insure maximum heat transfer between the pellets and the tube itself. The tubes are then capped. After a long series of rigidly monitored inspections, the individual tubes are placed in fuel "bundles" ready for use within the reactor core.

Lets examine next the events which occur within the fuel pellets to initiate and sustain power generation.

Fission Procedure

There are four types of neutrons: fast, thermal, delayed and immediate. Immediately after fission, all neutrons released are fast neutrons and achieve thermal velocities only as a consequence of collision with smaller atoms. Fast neutrons achieve velocities about 80% of the speed of light, while the thermal neutron velocities are about one mile per second.

About 99% of the neutrons are released immediately; the remainder are classified as "delayed neutrons," i.e., they experience an average "delay" of 14 seconds. About 88% of the heat produced in a reactor is a consequence of the kinetic energy from fission; 12% of the energy release is in the form of radiation. Radiation in fission reactors includes alpha and beta particles and gamma rays. Alpha emission, associated with heavy nuclei, does not constitute a source of primary concern to the reactor or its components.

Controlling Fission Reactions

Size and sophistication notwithstanding, the power output of most nuclear reactors is controlled by a single mechanism which regulates the "population" of neutrons in a reactor core. Both routine and emergency control procedures utilize substances such as boron and cadmium, either in liquid or solid form, that have very high neutron absorption coefficients.

These substances are inserted into the reactor core by means of adjustable rods called control rods or by injection of liquids containing boron. Sometimes both techniques are utilized as routine operations. In addition to the regulating rods utilized for routine control purposes, a supplementary set (referred to as safety rods) is utilized to permit rapid shutdown under emergency conditions.

When fuel is loaded into the reactor, a number of the regulating and safety rods are set in the "In" position. When the reactor is fully loaded and ready for operation, it is placed in operation by withdrawing the safety rods and partially withdrawing the regulating rods. The latter step is carried out gradually and in response to signals from neutron counting instruments used to monitor the rate of fission. Once the reactor is critical, meaning that the chain reaction had become self-sustaining, the regulating rods are adjusted as necessary to maintain steady-state operating conditions.

If the operator wants to increase the power output, the regulating rods are further withdrawn. The neutron "flux" within the core increases, and additional heat is generated through the kinetic energy released by the fission process. If the operator wants to decrease power output, the regulating rods are more fully inserted. Additional neutrons are absorbed, and the reactivity of the reactor is reduced.

From the time the nuclear fuels are processed, placed in pellets and fuel rods, and loaded into the reactor, the only radioactivity present is that introduced through natural decay. Since natural decay is much too low to achieve a chain reaction, reactors are "started" through the introduction of an encapsulated unit containing a radioactive mixture of Americium, Beryllium and Curium which provides about $3.2(10^9)$ neutrons/sec. After the chain reaction is initiated within the core, the process becomes self-perpetuating and control is achieved through neutron absorption.

A second phenomenon related to reactor operation is loss of "reactivity." As fuel is consumed, fission products are formed within the fuel rods. Unfortunately, in terms of efficiencies, many of these substances absorb neutrons wastefully via parasitic absorption which reduces reactor reactivity over time.

A useful analogy is that of a fire's being gradually smothered by the buildup of carbon dioxide. To compensate for this loss of reactivity and for the consumption of fuel, it is necessary that new fuel rods contain a higher power output. The extra fuel provides excess reactivity that is initially kept in check through insertion of control rods and eventually utilized through gradual withdrawl of the control rods.

The fast neutrons liberated in a chain reaction must be slowed to "thermal" speeds if neutrons are to be absorbed by the U235 fuel used in light water reactors. A material which possesses the capability of slowing neutrons quickly and which at the same time has little tendency to absorb neutrons unproductively is a moderator.

Neutrons have a mass approximately the same as that of the hydrogen atom. Therefore, materials containing a concentration of hydrogen or other light-weight atoms are the most effective moderators. Materials commonly used as moderators include water, heavy water (deuterium), oxides and graphite.

Neutrons liberated in a typical LWR lose speed through collisions with the moderating fluid, and it is estimated that 30,000 such collisions per neutron are required. Neutrons are then more likely to be absorbed by the fissionable fuel.

Some reactors use highly enriched fuel which can sustain a chain reaction on fast neutrons, thus eliminating the need for moderators. Those reactors and systems will be discussed in the unit on breeder reactors.

In the typical light water reactor, the number of neutrons available under average operating conditions is about 5 x 10^{13} per square centimeter/per second. In all reactors, neutron sensing instruments are used to monitor the neutron populations within a reactor core. In reactors designed for central station service, several independent neutron monitoring circuits are employed and are wired into safety mechanisms that automatically stop the reactor if neutron levels exceed pre-determined limits.

Shut-down is achieved through the rapid insertion of control rods or, in some reactors, through simultaneous injection of neutron absorbing "poisons" into the reactor core. The Nuclear Regulatory Commission (NRC) requires that nuclear safety mechanisms operate in a "fail-safe" manner, meaning that if any component fails, the emergency control mechanism is automatically placed in operation. It is reassuring to bear in mind that the design and operational requirements for emergency control procedures require that 80% of the control rod insertion be achieved in a small fraction of a second.

CHAPTER 11

FISSION REACTORS

Although three major types of fission reactors are in use in the U.S. today, the majority consist of boiling water reactors (BWR) and pressurized water reactors (PWR). The third type, the high-temperature gas-cooled reactor (HTGR), is not in common use and will not be discussed extensively. (See Figure 11-1 and 11-2)

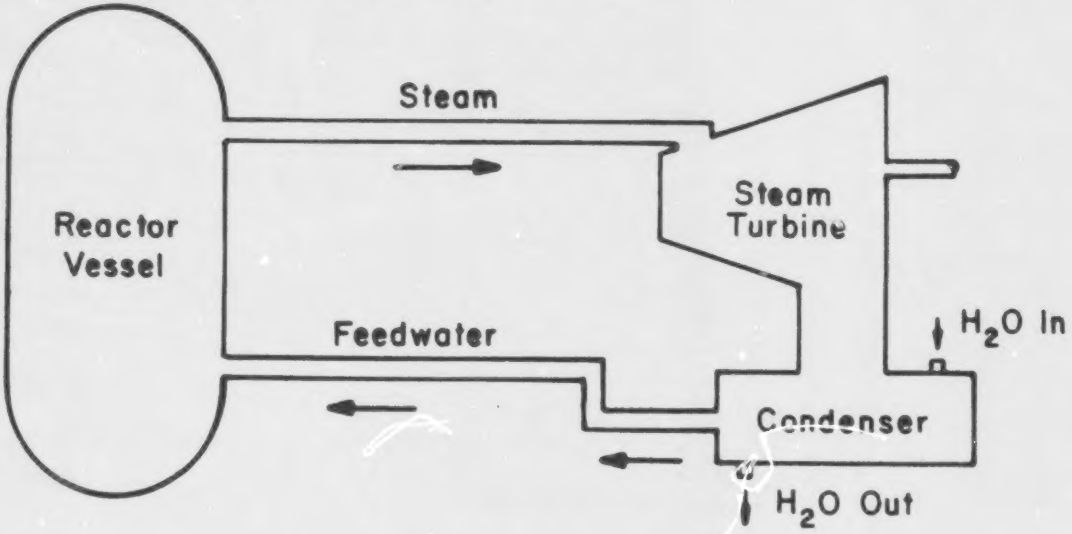
As one examines schematics for the BWR and PWR, it becomes apparent that with the exception of the heat source and the external appearance, BWR's and PWR's are very much like a typical fossil-fueled thermal generating plants. Unlike fossil-fueled plants, however, nuclear plants in normal operation emit no visible air pollutants and emit less radiation than is contained in the combustion products typical of many coal-fired plants.

Visually, little difference is evident between a BWR and a PWR; however, in the design and operating sense, significant differences do exist. Similarities include the fact that both BWR's and PWR's are net consumers of nuclear fuel and are thus classified as "burner" reactors. Both systems utilize massive, carefully designed and constructed steel vessels to contain the nuclear fuel, coolant-moderator, and steam generating portions of a typical electrical generating facility. Both use slightly enriched uranium in the form of uranium dioxide pellets contained in cladding tubes made of an alloy of zirconium, and both use de-mineralized water as the coolant moderator.

On the BWR, heated water under approximately 1,000 pounds per sq. inch (psig) is circulated through the reactor core and acts both as a moderator and coolant. The fluid becomes steam in the upper part of the vessel and is conducted through a steam separator to remove water droplets before entering the

Figure 11-1

BOILING WATER REACTOR


Steam
Reactor Vessel
Steam Turbine
Feedwater
H_2O In
Condenser
H_2O Out

PRESSURIZED WATER REACTOR

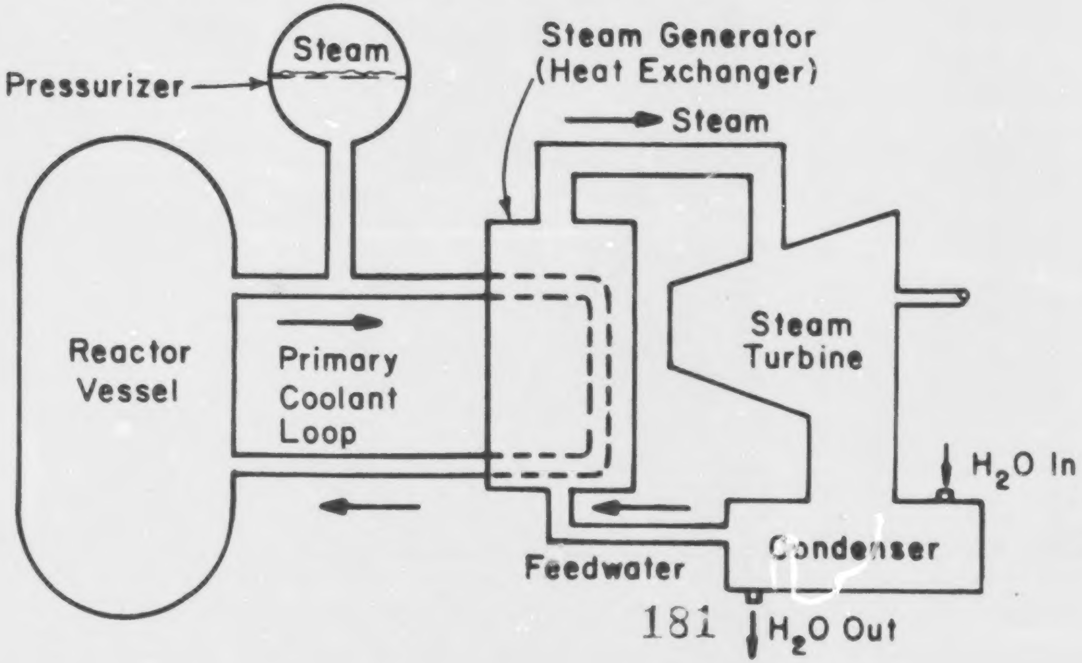
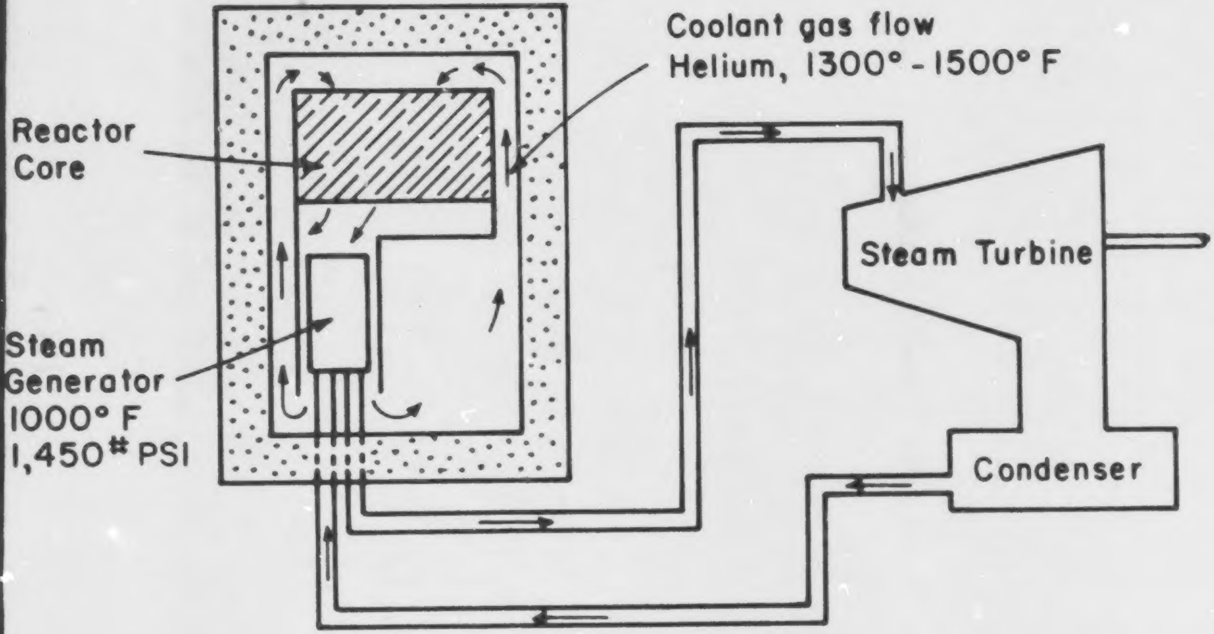

Steam
Pressurizer
Steam Generator (Heat Exchanger)
Steam
Reactor Vessel
Primary Coolant Loop
Steam Turbine
H_2O In
Condenser
Feedwater
H_2O Out

Figure 11-2


Coolant gas flow
Helium, 1300° - 1500° F
Reactor Core
Steam Turbine
Steam Generator 1000° F 1,450# PSI
Condenser

P. E. Pankratz 75

large line leading to the steam turbine. Within the turbine, the kinetic energy of the high pressure steam is converted to mechanical energy through turbine rotation. The steam then exhausts to the condenser, the resulting condensate is preheated and pressurized, and the fluid is then returned to the reactor.

Boiling water reactors tend to have a slightly higher environmental contamination potential than PWR's because of the fact that the coolant which flows directly past the fuel elements may be contaminated by leakage of radiation contained within the fuel rods. The steam phase can therefore conduct radioactive materials through all components of the steam generating, energy transformation and cooling cycles.

Two environmental protection advantages of BWR's are:

- Because of the lower pressures maintained in the reactor, turbine and coolant loops, leakages are less likely to occur.
- Increased temperatures, and accompanying decreased moderation, retard neutron reactions in nonroutine occurrences.

In addition to the "direct cycle" BWR, another type of boiling water reactor (indirect cycle) utilizes an external heat exchanger just as does the pressurized water reactor. The overall plant efficiency of the typical BWR is approximately 34%.

Pressurized water reactors (PWR's) take advantage of the principle that under very high pressures, the boiling point of water can be increased. The Carnot Formula for calculating the theoretical efficiency of heat engines holds that as the temperature is increased, the efficiency of a given unit will increase.

A primary difference between a BWR and PWR is that the latter employs steam generators and uses secondary loops between the steam generator and the turbine. Cross-sectional examination of a typical PWR would disclose that except for a gas space in the pressurizer, the pressure vessel and primary loop are completely filled with water. During operation (as in BWR's) the liquid coolant moderator contained within the primary loop is highly radioactive.

Maintenance of a liquid condition within the primary loop is assured through the use of an electrically heated pressurizer in the upper part of the primary loop system. Under a pressure of 2,000 psig, the temperature of the typical PWR would be 636 degrees F. versus 545 degrees F. for a typical BWR operating under 1,000 psig.

The PWR primary coolant passes through an external heat exchanger (steam generator), transfers its heat to the material contained within the steam generator. The heat exchanged to the steam generator primary system converts water in the secondary loop to steam which is fed into the turbine to produce power. Condensation and recycling to the steam generator then occur.

In both BWR and PWR plants, an external source of cooling water is circulated through the condenser and discharged to one of several heat sinks available.

Environmental Protection

Routine operation of nuclear-fueled power plants produces a variety of radioactive materials that are released as solids, liquids, and gases. The principle radioactive materials formed are fission products, i.e., the ashes of nuclear fuels which are retained within the fuel rods themselves.

Routinely, small quantities of both gases and liquids are released after appropriate delay-and-decay techniques, under conditions acceptable to the NRC. Despite the fact that differences of opinion exist between the proponents and opponents of nuclear-fueled power generating facilities, there is a consensus that adequate safeguards must exist to protect the environment and citizens in the event of malfunctions. (See Table 11-1)

Design and environmental protection requirements have created five lines of defense for high level wastes in the fuel of nuclear generating facilities. The first defense mechanism is the highly dilute nature of the UO_2 itself.

The second is the use of highly effective zirconium fuel cladding which ensures retention of radioactive materials within the fuel rods.

The third defense is the provision of emergency control procedures for both neutron absorption and core cooling.

The fourth safeguard is the design and construction specifications for the reactor vessel itself, and the fifth is the NRC requirement that radioactive components of generating units be housed in a containment structure meeting rigid design, construction and performance standards.

Once a utility decides that a nuclear power plant is needed to serve the electricity requirements of its area, a massive regulatory apparatus is set in motion to assure public and environmental protection. One of the very first procedures involves the filing of an environmental analysis of the aquatic, terrestrial and atmospheric impacts of such a unit, as well as its economic, social and resource consequences.

Table 11-1

COMPUTE YOUR OWN RADIATION EXPOSURE

We live in a radioactive world. Radiation is all about us and is part of our natural environment. By filling out this form, you will get an idea of the amount you are exposed to every year.

	COMMON SOURCE OF RADIATION	YOUR ANNUAL INVENTORY
WHERE YOU LIVE	Location: Cosmic radiation at sea level Add 1 for every 100 feet of elevation 1 x ________ Typical elevations: Pittsburgh 1200; Minneapolis 815; Atlanta 1050; Sequoia National Park 6400; Las Vegas 2000; Denver 5280; St. Louis 455; Yosemite Valley 4000; Salt Lake City 4400; Dallas 435; Bangor 20; Sacramento 30; Spokane 1890. (Coastal cities are assumed to be zero, or sea level.)	40 ________
	House construction: Wood 50; Concrete 70; Brick 75	________
	Earth (Minerals): U. S. Average	45
WHAT YOU EAT, DRINK & BREATHE	Water, Food, and Air: U. S. Average	30
HOW YOU LIVE	Jet Airplanes: Number of 6000-mile flights ________ x 4	________
	Television Viewing: U. S. Average	.1
	X-ray diagnosis and treatment: average yearly exposure	70
	COMPARE YOUR DOSE TO THE U.S. AVERAGE OF 200	SUB TOTAL ________ mrem
HOW CLOSE YOU LIVE TO A NUCLEAR PLANT	At site boundary: Number of hours per day ________ x 0.2 One mile away: Number of hours per day ________ x 0.02 Five miles away: Number of hours per day ________ x 0.002 Over 5 miles away: ________ None	________ ________ ________

TOTAL ________ mrem

One mrem per year is equal to: Increasing your diet by 4%

Taking a 4-5 day vacation in the Sierra Nevada

The siting of nuclear reactors is of particular significance in California with its many active earthquake faults. Concerns regarding seismicity seem to relate primarily to possible consequences of a strong temblor which might succeed in rupturing some of the main steam or coolant pipes to the reactor.

Accidental rupturing of the reactor plumbing could result in what is termed, "loss of cooling accident" (LOCA). In recognition of the need to eliminate to the greatest extent possible this type of accident, all lines entering and leaving the reactor vessel are protected by what is known as seismic snubbers. These permit limited pipe movement, but not to the extent that ruptures might occur. In several instances in recent years, nuclear plants nearing completion have been halted in the final stages of construction by the "discovery" of hitherto unknown faults near the construction site. Further analysis of design criteria and protection safeguards, and possible revision in the engineering specifications, is required before construction can be resumed.

Nuclear power plants pose hazards of a different kind than do fossil-fired units. Part of the reason is that under intense neutron radiation, metals behave in an unusual fashion. Those containing impurities develop voids and internal stress fractures which could violate the integrity of important vessel components. In recognition of the altered behavior of metals under conditions of high neutron flux, temperatures and pressures, the metal from which the reactor vessel is made is subject to careful analysis and control from the time of the smelting of the ore through final fabrication of the vessel itself.

All reactor vessel manufacture involves the use of X-rays and sophisticated ultrasonic test equipment to confirm that the vessels meet or exceed all design specifications. In addition to rigorous testing at the factory, reactors, steam generators and related components undergo painstaking examination and testing after delivery. To minimize corrosion, the reactor is lined with stainless steel. This stainless surface assists not only in reducing the loss of neutrons by providing a reflective surface, but it also eliminates to a major extent corrosion products in coolants.

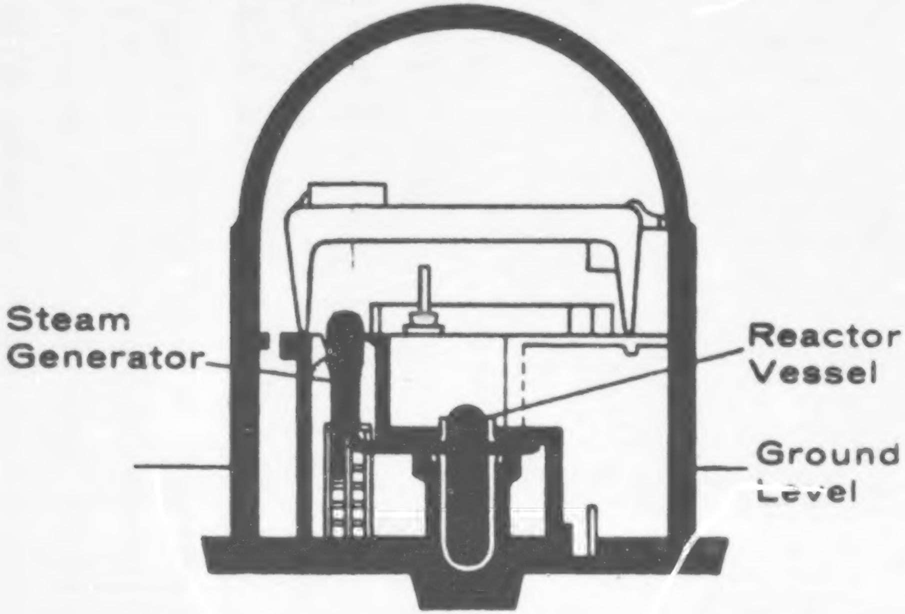
The last lines of defense required of reactors in the U.S. (but not in the Soviet Union or a number of other European countries) are site exclusion areas and containment vessels, large, extremely strong, steel-and-concrete structures. The containment structure appears less impressive than it actually is, because a major part of the unit is underground. The lower part of the containment structure serves as a foundation for all of the major components of the reactor.

Constructed with extremely thick walls of concrete, three to four feet in thickness and reinforced with steel bars about three inches in diameter, the containment structure is lined with a leak-proof steel shell. The containment components are designed so that if a primary steam or coolant line should rupture accidently and release its contents, the steam and radioactive products would be retained within the containment structure and not released to the environment. (See Figure 11-3)

To insure the adequacy of design and construction, containment structures are tested prior to operation to make certain that they meet stringent anti-leak requirements. In addition, containment structures possess sophisticated air release valves, air conditioning and spray equipment, all of which are designed to insure the retention of accidental releases of materials.

Figure 11-3

CONTAINMENT STRUCTURE


Steam Generator
Reactor Vessel
Ground Level

An accident about which extensive controversy exists is referred to as the "China syndrome." In the case of loss of coolant from a primary system, it is postulated by some that a complete meltdown of the core and its contents would ensue. In such an event, some hold that heat generated by uncontrolled fissionable materials would result in the melting of the bottom of the vessel. The molten fissionable material would theoretically melt its way through the concrete containment structure down into the earth.

In 1957 the Atomic Energy Commission asked the Brookhaven National Laboratory to project the consequences of a "maximum credible accident" which would release 50% of all the fission products of a nuclear reactor in close proximity to a city of one million persons.

The resulting report, titled WASH 740, was born in dispute that is yet to die away. WASH 740 estimated that the "maximum credible accident" could result in as many as 3,400 deaths, more than 40,000 casualties and property damages in the billions of dollars.

WASH 1400, a more recent examination, by a group of 60 specialists under the direction of Dr. Norman C. Rasmussen of the Massachusetts Institute of Technology, was completed in 1975. The approach employed in the study was to use the best engineering judgment to ascertain the probability of a major nuclear accident and then to estimate property damages, casualties and deaths.

The results of the the Rasmussen study differ significantly from those of WASH 740. Researchers concluded in WASH 1400 that there is one chance in a billion per year of being killed in a nuclear power plant accident. The study concludes that less serious accidents are far more probable than a major accident. Summaries of both WASH 740 and 1400 are available.

Radiation Standards

One of the major environmental advantages which nuclear-fueled electric plants hold over fossil-fueled plants is that there are no conventional products of combustion resulting from nuclear fission. Routine radioactive emissions do occur; however, such releases are closely controlled and monitored. The NRC has long-standing regulations limiting the maximum exposure to the general population. These have been regularly reviewed and tightened several times.

Although general agreement is lacking on the relative hazards of routine releases, NRC regulations require that there be no more than 5 millirems public exposure, per year, per reactor, at the boundary of a nuclear facility. From the inception of regulations governing maximum exposure levels, each revised regulation has decreased the permitted exposure. Clearly, the regulatory philosophy ("as low as practicable") seems to be that maximum levels should be decreased until research on large populations shows clearly that conservative limits are inappropriate.

This seems a reasonable policy. A comforting thought for those who may tend to be concerned about radioisotope releases by nuclear facilities is that actual releases average substantially less than 10% of the permitted maximum. Regardless of one's adherence to either the threshold or zero-tolerance theories concerning the adverse effects of ionizing radiation, the practice of restricting routine releases to the lowest possible minimums merits endorsement.

A problem of apparent increasing concern is the possibility that fissionable material might be stolen and used to manufacture an explosive device. For those who have intimate knowledge of the vast number of specific conditions which must be met to develop an explosive device, such fears seem to be unwarranted.

That fact notwithstanding, it is extremely difficult to develop a sound plan of defense against the hypothetical theft of nuclear materials. Until the general public becomes knowledgable concerning the significant difficulties associated with developing an explosive device, additional precautions to avoid the possible diversion of fissionable materials will be required.

Recent legislation restricts the opportunity for persons to visit nuclear facilities. For example, persons who visit the Sacramento Municipal Utility District Rancho Seco reactor should take advantage of the opportunity to discuss with tour guides the elaborate precautions designed to insure against unauthorized entry to the reactor site. It is assumed that as newer units come on-line similar security provisions will be required.

Licensing and Inspection Procedures

Although a recapitulation of the entire process involved in securing approval for the construction of a nuclear generating station will be included in an appendix, a listing of the major agencies involved and the approvals required may prove enlightening. Using the San Onofre nuclear generating station as an example, the agencies and their primary areas of jurisdiction are:

1. Nuclear Regulatory Commission: construction permit, operating license, special nuclear material license and the individual operator's license.
2. The U.S. Army Corps of Engineers: permit to install a temporary bulkhead and to deposit sand, permit to construct in navigable waters and permit to discharge in navigable waters.

3. California Public Utilities Commission: certificate that present and future public convenience and necessity require or will require the construction of San Onofre Units 2 and 3 and related electric transmission facilities.
4. State Department of Public Health: involvement in radiological monitoring and program approval.
5. The Resources Agency of California: involvement in the siting agreement.
6. The State Lands Commission: sand disposal and a temporary working area.
7. California Regional Water Quality Control Board, San Diego Region: disposal and industrial waste discharge resolutions.
8. State Water Resources Control Board: certificate of compliance with water quality standards.
9. The U.S. Coast Guard: aids to navigation agreement.
10. U.S. Marine Corps: soil disposal agreement and easements for transmission lines, telephone lines and road relocation.
11. The State Division of Highways and the U.S. Marine Corps: series of easements for transmission lines, highway relocation, drainage, encroachment permits, etc.
12. San Clemente City Council: agreement to furnish water service during construction.

Lengthy though the list is, this is just a brief introduction to the details involved in developing a nuclear-fueled facility.

Nuclear Fuel and Waste Storage

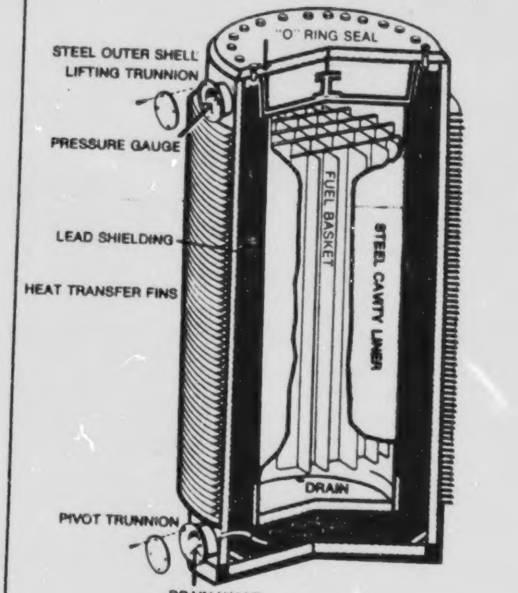
In comparison to fossil-fueled units, and particularly coal fired plants, the fuel volumes for nuclear plants are miniscule. Once each year the reactors are shut down to permit replacement of one-third of the fuel assemblies. Upon replacement, the spent fuel bundles are stored underwater for some months to permit short-lived radioactive materials to decay. For short-term storage, the fuel bundles are transported in specially designed shipping casks to fuel reprocessing centers. (See Figure 11-4)

Most spent fuel is now being stored either on-site at the nuclear plants themselves or in government storage facilities until the completion of a new spent fuel reprocessing plant at Barnwell, S.C. This plant, however, will be able to handle only about half the reprocessing demand through 1985; therefore, on-site storage will be with us for some time, perhaps well into the 1990's.

(Some of the most hazardous isotopes produced in nuclear fission units are: iodine 129, plutonium 239, strontium 90, cesium 137, tritium, krypton 85, and iodine 131. All are harmful, but iodine 131 and cesium 137 are particularly hazardous, because they concentrate in some of the food chains upon which man is dependent. Most of the radioisotopes, however, do not have the concentration potential and are not of as great concern.)

At the fuel reprocessing plant, the fuel bundles are dissolved in acid and the materials separated and purified. About two-thirds of the original U235 has been consumed, and the rest is eligible for recycling and reuse. One ingredient which is the subject of considerable discussion (and in some cases controversy), is Pu 239, produced through neutron activation of U238. In the average light water reactor, about 0.55 grams of Pu 239 are produced for each gram of fissile material consumed.

Figure 11-4


"O" RING SEAL
STEEL OUTER SHELL
LIFTING TRUNNION
PRESSURE GAUGE
FUEL BASKET
STEEL CAVITY LINER
LEAD SHIELDING
HEAT TRANSFER FINS
DRAIN
PIVOT TRUNNION
DRAIN VALVE

Courtesy Atomic Industrial Forum, Inc.

Spent Fuel Shipping Cask

One of the most controversial aspects of nuclear-fueled generating units is disposal of the high level radioactive wastes which remain after the spent fuel rods are reprocessed. For example, strontium 90 and cesium 137 have long half-lives which dictate confinement for extended periods. While "delay and decay techniques" may be applied to radioactive materials with short half-lives, those with long half-lives, such as strontium, cesium and plutonium require confinement for hundreds or even thousands of years.

Since the early 1940's the federal government has stored millions of gallons of wastes with something less than 100% success. The high level radioactive waste storage vessels must be strong physically and resistant to thermal and corrosion stresses. Although the large majority of the wastes have been stored without incidents, leaks have occurred in a few cases.

Controversy exists as to the environmental hazards associated with the leaks. As a consequence, NRC has an aggressive program to solidify liquid radioactive wastes. Although the federal government has been under considerable pressure to select a long-term storage method for high level radioactive wastes, no decision has yet been announced.

THE PRICE-ANDERSON ACT

In 1957 Congress passed the Price-Anderson Act which placed the financial responsibility for possible nuclear power plant accidents on the public. The liability for any single nuclear accident was established at $560 million. Private insurance carriers now cover more than $100 million of this.

Because Congress sought to encourage the development of nuclear power and simultaneously to protect public utilities from severe financial losses in the event of a nuclear accident, the Price-Anderson Act required every nuclear plant to carry the maximum insurance available from private carriers while providing an additional $478 million in Federal indemnity.

In the event of an accident the maximum allowable that could be claimed would be $560 million. For example, if an accident produced $1,600 million in claims, claimants would receive approximately 1/3 restitution.

The original 1957 act, covering a 10-year period, was extended for a second 10-year period in 1965. In August, 1974, Congress passed a bill which extended the Price-Anderson to 1987 and increased liability coverage from $560 million to $1 billion.

CHAPTER 12

GEOTHERMAL

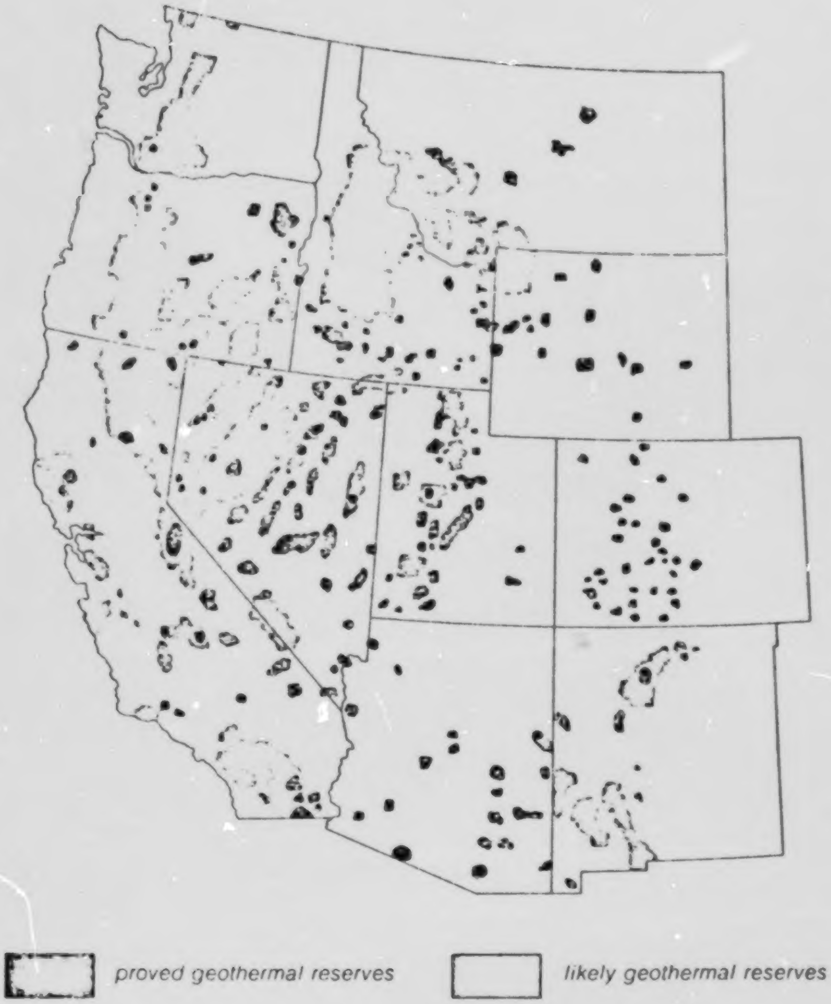
Congress moved to encourage geothermal development in 1970 through enactment of a geothermal steam act which established a leasing system for federal lands. In 1971 the U.S. Geological Survey designated more than 1 million acres of California lands as Known Geothermal Resource Areas (KGRA). In 1974, competitive bidding for leases of federal lands in three areas of California were opened: (1) Geysers - Cobb Mountain area, Sonoma County, (2) Mono Lake - Long Valley - Casa Diablo area, Mono County, (3) Imperial Valley - Salton Sea area, Imperial County. (See Figure 12-1)

Test wells were drilled near Niland, California, in the Imperial Valley in the 1920's. Although steam was found in abundance, the project was abandoned because of the failure to contract for electricity.

An early attempt was also made to develop the Geysers in Northern California in 1922. Drillers successfully tapped the steam source, but piping and turbines available at that time could not withstand the corrosive and abrasive effects of the steam. Additionally, hydroelectric power was then more economical and the project was abandoned.

The next effort to tap the Geysers energy supply occurred in 1955. Availability of improved materials and economic prospects allowed the first generating unit of 11,000 kw to go on-line in 1960. Expansion at the Geysers has continued since that date and has produced the largest geothermal electric plant in the world.

Figure 12-1


proved geothermal reserves
likely geothermal reserves

Most of the potential and proved geothermal fields in the United States are located in the West (Data from Muffler 1973)

Sources of Geothermal Energy

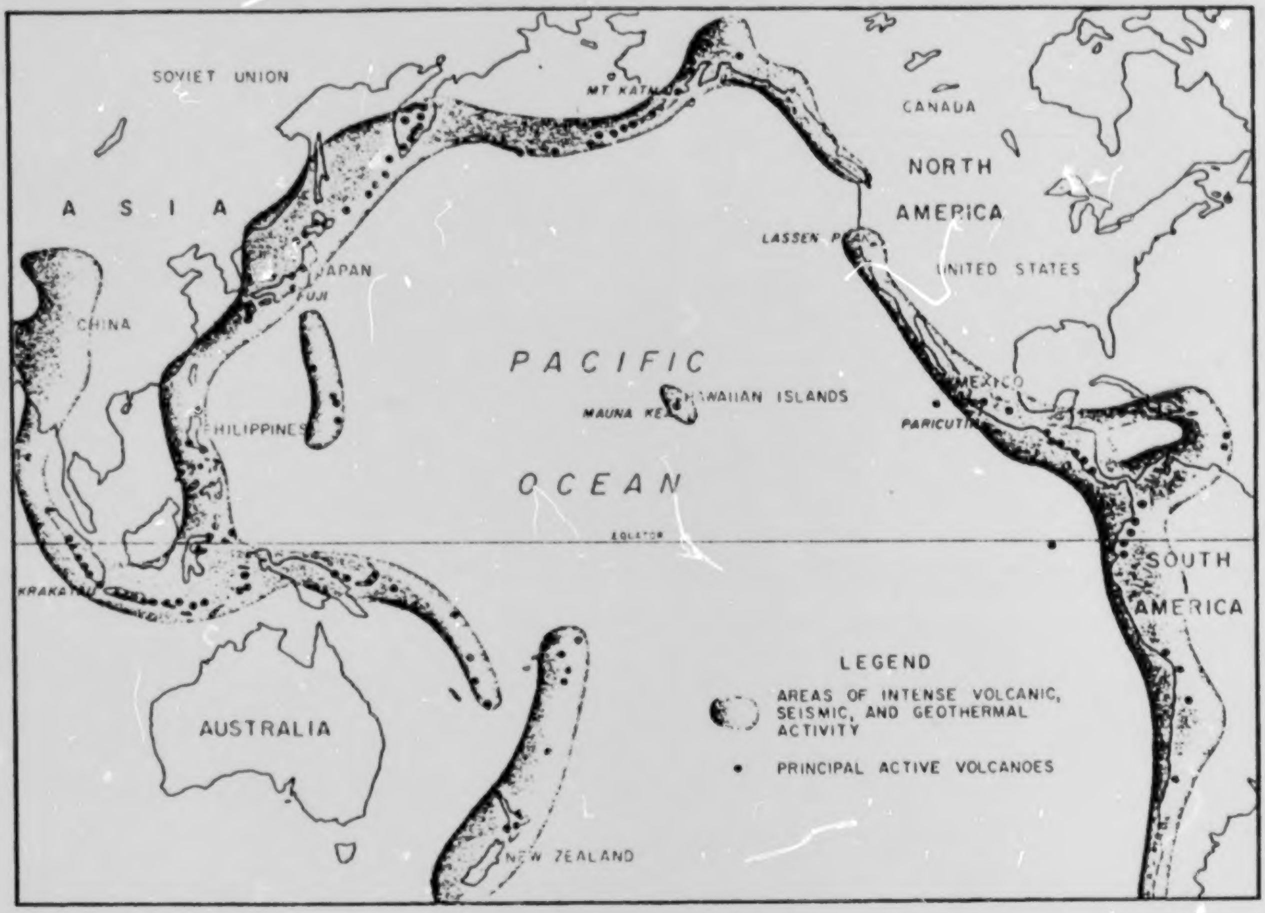
Three theories exist as to the source or sources of the heat energy contained within the globe. They are: (a) residual heat remaining from the creation of the earth by components of the solar system, (b) heat generated by friction associated with the movement of major tectonic plates riding on the earth's surface, and (c) heat energy released by decay of radioactive materials. The accuracy of each of these theories is a matter of extensive conjecture. Let's take a closer look at each of them.

Proponents of the tectonic theory hypothesize that the outer crust of the earth (averaging about 30 miles in thickness) "floats" on slowly moving magma. Tectonic plate movement, calculated at 5 to 7 centimeters a year, produces heat as the plates rub and jostle each other. Such collisions trigger earthquakes and generate heat.

An examination of one of the earth's major seismic zones encircling the Pacific Ocean makes it clear why this vast region has been termed the "Ring of Fire." It is no coincidence that major faults and volcanoes are common to areas adjacent to the Ring of Fire. Whether volcanism and geothermal activity are consequences of the movement of tectonic plates or whether they result from intrusion of magma into the earth's upper crust remains a source of scientific dispute. (See Figure 12-2)

The second theory, that the earth's core heat is residual heat carried over from the formation of the earth, has relatively little support. Opponents have pointed out that for the earth's surface to contract enough to create mountain ranges, the temperature difference between the original heat regime and the existing heat regime would have had to be much greater than the evidence supports.

Figure 12-2


SOVIET UNION
A S I A
CHINA
JAPAN
FUJI
PHILIPPINES
KRAKATAU
AUSTRALIA
NEW ZEALAND
MT KATMAI
CANADA
NORTH AMERICA
LASSEN PEAK
UNITED STATES
PACIFIC OCEAN
HAWAIIAN ISLANDS
MAUNA KEA
MEXICO
PARICUTIN
EQUATOR
SOUTH AMERICA
LEGEND
AREAS OF INTENSE VOLCANIC, SEISMIC, AND GEOTHERMAL ACTIVITY
● PRINCIPAL ACTIVE VOLCANOES

PACIFIC RING OF FIRE

Proponents of the radioactive element decay theory point out that radioisotopes now contained in the earth are logical products of a long radioactive decay series. Calculations demonstrate that the half-lives of the various elements in the decay chain would establish the original radioactive material at about the same age as that estimated for the earth.

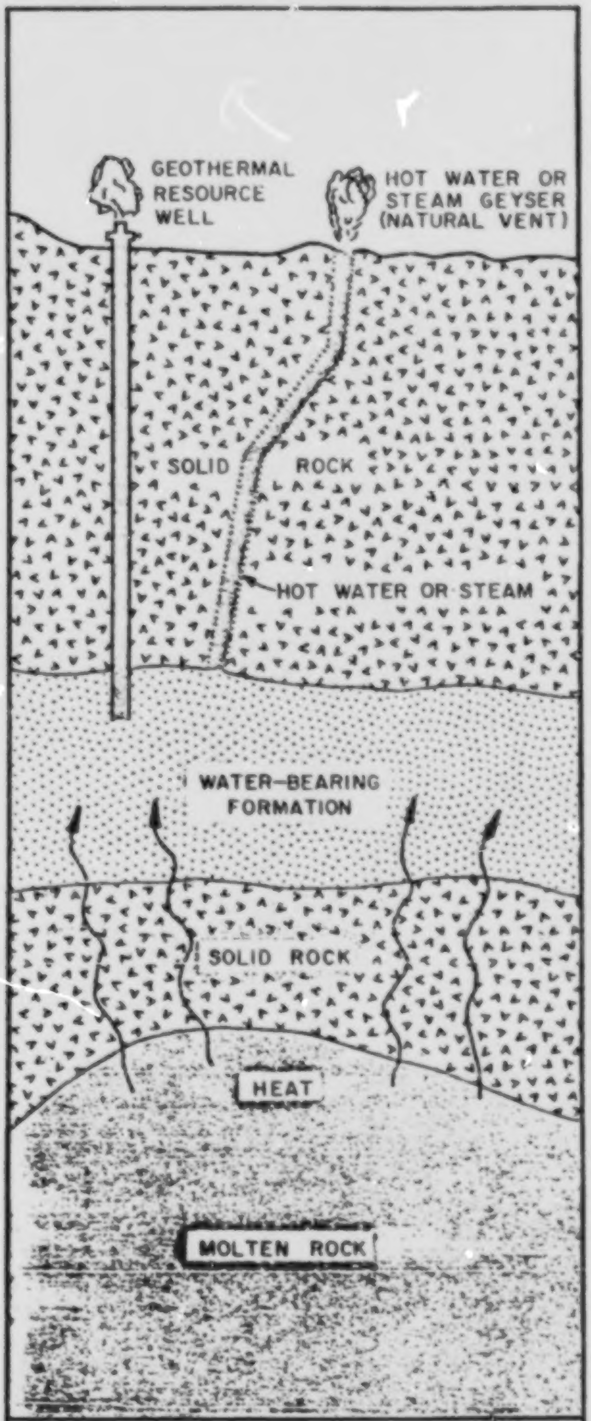
Regardless of the various theories, the fact remains that the temperature of the earth is fairly constant (2500 - 3500 degrees F) to the inner edge of the crust. The last 30 miles of the crust apparently enjoy a fairly uniform temperature rate decrease of approximately 1°F for each 100 ft. toward the earth's surface. You might reverse the procedure and say that if the temperature at the surface is 43°F, one could expect a temperature of 63°F at 2,000 ft. This uniform temperature increase with depth is particularly apparent in the western half of the U.S.

Geothermal Resource Types

Three basic types of geothermal energy sources exist: (a) natural reservoirs containing superheated "dry" steam, (b) reservoirs containing a mixture of superheated water (generally mineral laden) and steam, and (c) hot rock (dry reservoirs where neither steam nor water normally exist but which may be utilized for steam production. (See Figure 12-3 and 12-4)

Although vapor dominated, or dry steam, geothermal deposits today constitute the primary form of geothermal energy used in the production of electrical power, few serious exploration attempts on a world-wide basis have been undertaken. While opinions on the physical processes responsible for vapor dominated systems vary, there appears to be general agreement that such systems are characterized by very high heat supplies and very low recharge rates.

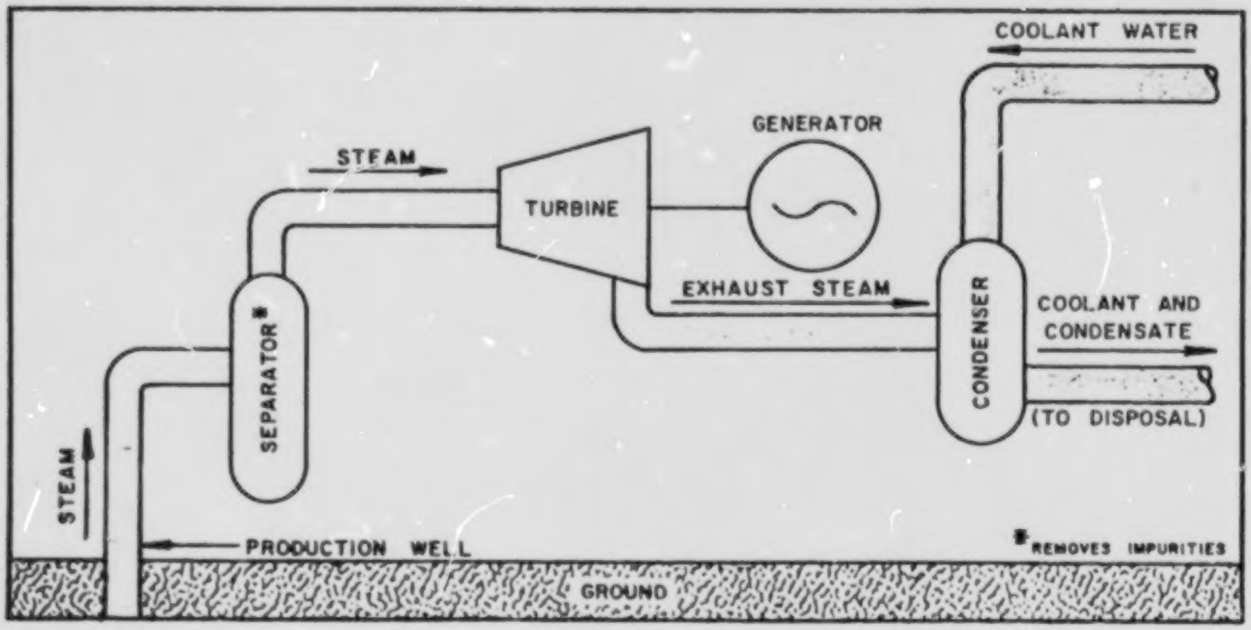
Figure 12-3


GEOTHERMAL RESOURCE WELL
HOT WATER OR STEAM GEYSER (NATURAL VENT)
SOLID ROCK
HOT WATER OR STEAM
WATER-BEARING FORMATION
SOLID ROCK
HEAT
MOLTEN ROCK

CROSS SECTION OF GEOTHERMAL ANOMALY

Figure 12-4

SIMPLIFIED SKETCHES OF METHODS FOR GENERATING


COOLANT WATER
GENERATOR
STEAM
TURBINE
EXHAUST STEAM
COOLANT AND CONDENSATE
(TO DISPOSAL)
SEPARATOR*
CONDENSER
STEAM
PRODUCTION WELL
*REMOVES IMPURITIES
GROUND

FROM VAPOR-DOMINATED RESOURCE

The portion of the discharge fluid that exceeds the recharge rate is apparently supplied by water stored in large fractures within the associated rock formations. The relative ease with which vapor dominated systems can be exploited accounts for the fact that approximately 75% of the world's present geothermal electric production is of the vapor dominated type. Dry steam reservoirs account for only 5% of the world's total geothermal resources.

Temperatures and pressures in vapor dominated systems vary considerably. At the Geysers, well-hole temperatures are about 450°F at a residual pressure of 450 to 500 lbs. per sq. inch.

Hot water, or brine, geothermal reservoirs, such as exist in the Salton Sea - Imperial Valley area of California, are characterized by water instead of dry steam. Vapor may be present but is generally in small amounts in shallower pressure zones. In a hot water system, temperatures increase with depth. Also, a high percentage of dissolved minerals can significantly increase the difficulties associated with both drilling and electric generation.

Silicates, carbonates and other compounds can (and do) plug wells and pipes and can drastically reduce heat exchange coefficients. The fluids themselves pose disposal problems, once used. Additionally, high corrosivity can result from supersalinity, high carbon dioxide or acidity from H_2SO_4. Despite the much larger deposits of hot water worldwide, technological problems may delay widespread development at least over the short-term.

Only minor research efforts are being directed toward utilization of "hot rock" geothermal systems. As noted earlier, the lion's share of geothermal heat, within reach of the drilling bit, is believed to be in the form of dry, hot rock. Some conservative projections, on the assumption that hot rock development is technically feasible, hold that this form of geothermal energy could become a major source of electrical energy in the future. In the Western U.S, subsurface temperatures increase at a rate of about 1°C for each 100 feet penetration.

One proposed method of tapping these hot rock deposits is to create fractures in the hot rock formation, by means of either conventional or nuclear explosives and then to circulate water from the surface through the fractures. Once converted to steam (or superheated water), the fluid is returned to the surface where it drives a turbine-generator, is condensed and reinjected.

For hydro-fracturing a series of collector wells is drilled around a central injection well, and the intervening rock is fractured by high pressure water injection. Theoretically, water pumped into the central well under high pressure could be superheated by the deep hot bedrock and returned to the surface through the peripheral wells.

Efforts to date on the two hot rock techniques cited have been experimental, but results are encouraging. If the hot rock liquid-to-steam conversion technique can be developed into a workable procedure, and if techniques for economically drilling into the hot rock formations can be developed, the utilization of this form of geothermal energy could become commonplace. Geothermal generation would not then be bound to the relatively narrow seismic and thermal areas associated with tectonic activity.

Stanford University has indicated that the key to the development of the hot dry rock system is the technology of rock fracturing. A major program of fracturing research is needed to test present technology and to develop more effective methods. Additionally, a national program to improve geothermal drilling in depths beyond 20,000 ft. is essential.

Clearly, the potential of hot rock geothermal energy appears to make it more deserving than research efforts thus far have indicated. With the hot rock process, the absence of dissolved minerals and noxious hydrogen sulfide gas is an additional dividend.

Development and Energy Conversion Techniques

Drilling geothermal wells provides challenges not normally encountered when drilling for petroleum or water. At The Geysers in Sonoma County, drillers use conventional muds to get through water bearing rock strata and then switch to compressed air. Both mud and compressed air act to seal off the well-bore, and both are satisfactory materials for "floating" rock cuttings to the surface. Air is substituted at steam depths, because the mud tends to plug and to seal off porous, steam-bearing, rock and fracture zones.

The high pressures and velocities of the steam encountered, sometimes approaching sonic speeds, accelerates wear and tear on the drilling string and complicates tool recovery. Drilling costs per foot increase exponentially with depth, while the probability of finding steam in economic quantities diminishes.

Steam produced at the Geysers is dry and slightly super-heated but contains minute quantities of particulates carried along with the steam. The particles are erosive and could be damaging if introduced into the turbine and steam control mechanisms. To minimize damage, undesireable solids are removed in large centrifugal separators attached to the steam line. Approximately 99% of the particles 10 microns or larger are successfully removed.

The static, shut-in pressure of the steam at the well-bore averages 450 to 500 lbs. per sq. inch and is reduced to about 100 lbs. at the turbine intake. The average, developed well yields about 150,000 lbs. of steam per hour. Hence, seven wells are typically required to serve each turbine, each of which uses about 1 million lbs. of steam per hour to produce 55 megawatts of energy. A conversion ratio of 20 lbs. of steam per kwh.

Overall efficiency of Geyser units is approximately 16%, considerably less than the 42% efficiency possible at the recently completed (1972) Unit 7 of PG&E's Pittsburgh Power Plant. The reason, of course, is that pressures and temperatures are much lower at the Geysers. While overall turbine efficiencies are low, production costs are similarly low, bettered only by hydroelectric units in the PG&E system.

A network of steam collection pipelines at the Geysers gathers the steam from the wells and delivers it to the generating plant free of moisture and particulates. The turbines operate with an inlet pressure of 100 lbs. per sq. inch, and an exhaust pressure of 4" mercury absolute. Present condensers are of the direct contact type; new units will employ surface condensers which are required by the hydrogen sulfide abatement systems to be employed.

Re-use of the steam condensate as cooling water eliminates the need for make-up water supplies. Approximately 80% of the turbine steam flow is evaporated in the cooling towers. Condensate not used for condenser cooling is reinjected into nonproductive steam wells. The influence of the injected condensate on recharge of the field is under study. No significant negative effects on the steam supply have been noticed to date.

Steam corrosivity and abrasiveness are continuing challenges. Following a long testing program, the Pacific Gas & Electric Company has determined that austenitic stainless steels show least deterioration. Aluminum alloys and chromium stainless steels show very slight overall wear but are susceptible to chemical pitting. Copper alloys, plain carbon steel and cast irons, show excessive loss. The results of an extensive testing program, demonstrated that the main steam lines, valves and strainers could be made of carbon steel since that material is not appreciably corroded by the dry steam.

The turbines, although of conventional design for lower temperature and pressure steam service, are constructed of erosion corrosion-resistant alloys. For example, the turbine blades are 13% chromium steel to minimize abrasion from particulate matter. The hydrogen sulfide in the steam oxidizes to sulfate in the condensate and combines with other compounds to become quite corrosive. As a consequence, all wetted parts of the condenser are of stainless steel. The piping for the condensers is either stainless steel or aluminum.

Although the cooling towers are of conventional design, special materials are used. The welded metal parts are stainless steel or aluminum and, in a few cases, coated cast iron. The cooling towers themselves are constructed of redwood, with the fill material currently of polyvinyl chloride. Other plastics have been utilized, but polyvinyl chloride is preferred because of its strength and fire-resistant qualities.

Hydrogen sulfide, present in small amounts (0.5%), causes minor problems with electrical equipment because of its chemical affinity for copper and silver. Corrosion effecting control equipment in the new units is policed by maintaining "clean" areas under slight positive pressure, with the air filtered through activated charcoal units.

Hot Water Geothermal Systems

Worldwide, there are only a few large power stations using geothermal brines, or hot waters. While vapor dominated geothermal fields do present interesting technical challenges, they are simple and straightforward compared to water dominated geothermal systems.

In a typical hot water system, the majority of the heat is transferred by the circulation of fluid rather than by conduction through the rock. The heated fluid, of lesser density, tends to rise and is replaced by the cooler more dense fluid supplied from the upper portions of the geothermal area.

A number of variations of the basic water dominated system exist. Classification can be based on differences in salinity, chemicals, temperatures, reservoir size and percentages of vapor present. Characteristically, and almost without exception, water systems are characterized by the large number of chemicals which are in solution and remain in solution as long as high pressure regimes exist.

A number of the chemicals possess very low solubility can under conditions of reduced pressure tend to precipitate or crystalize when brought to the surface. It is these characteristics which provide the challenge to engineers seeking to exploit hot water G-T systems.

Not surprisingly, the water dominated geothermal systems that are the highest in temperature also tend to be highest in SIO_2, CL, NA and other chemicals, including arsenic. Work by Fournier and Trousdell (1970) indicates that one of the best ways to evaluate subsurface brine temperatures is to analyze SIO_2 (silicate) content and the sodium-potassium-calcium ratios of such springs.

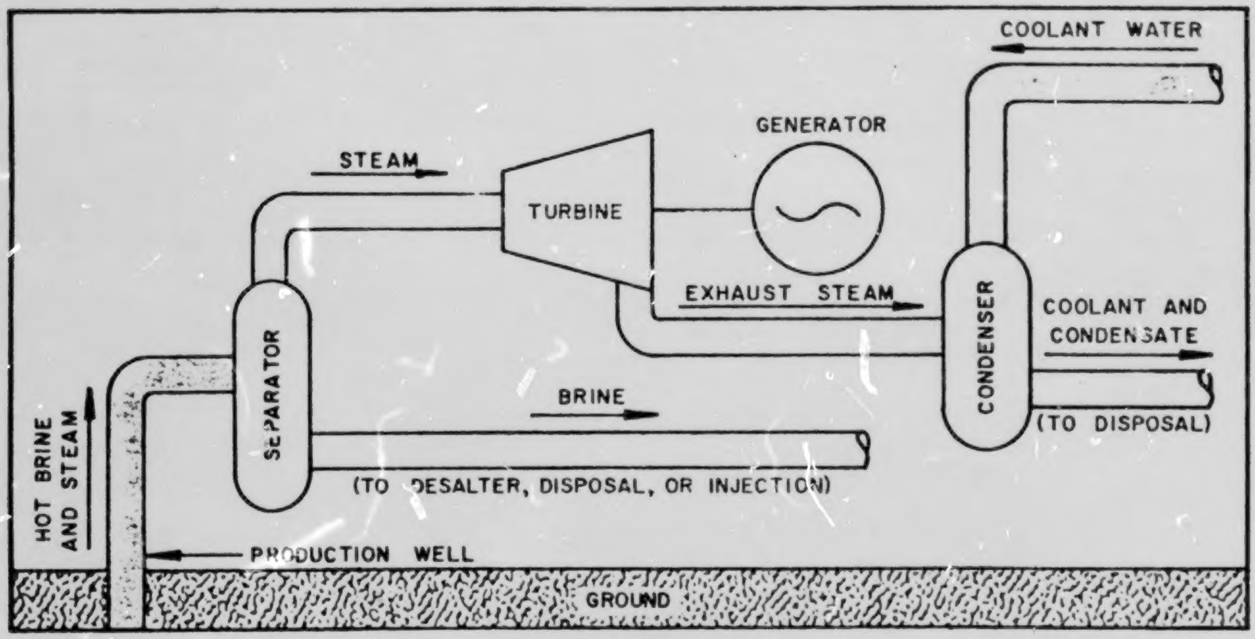
Of the materials in solution, silicate is by far the most troublesome. A number of approaches have been developed to circumvent silicate deposit problems. Figure 12-5 provides a schematic of a turbine utilizing the "open-method" of power generation from a water-dominated source. In such a system, operating experimentally in the Salton Sea area, the hot brine (about 360°C. and 26% salinity) leaves the well as a liquid and remains in liquid form until it enters a steam separator where one-third of the water "flashes" to steam. This steam fraction powers a turbine-generator in the conventional manner. After leaving the turbine the exhaust steam is sent to a condenser where it is cooled, condensed and discharged.

Steam flashed from hot brines frequently contains materials which are so corrosive that operation of turbines and pumps becomes impractical. The direct corrosive and abrasive effects of the water can be avoided through the use of a heat exchanger. (See Figure 12-6)

Through the use of an exchanger, the naturally heated material transfers its thermal load to a fluid (freon, isobutane) which is confined in a separate thermal cycle. This secondary fluid flashes to vapor at low temperature, and the vapor spins the turbine. Theoretically, such "binary" cycles reduce problems of scaling and corrosion. Two significant disadvantages of binary systems are the higher construction costs and reduced overall efficiencies of such units. The hot water, reduced in temperature from its passage thru the heat exchanger, is subsequently routed through the condenser and reinjected.

A number of fluids have been used in the binary, or vapor-turbine cycle, with butane the most prominent in the U.S. and freon in the USSR. One of the significant advantages of the vapor-turbine unit is that much lower condensing temperatures can be used than are possible with conventional steam turbine units.

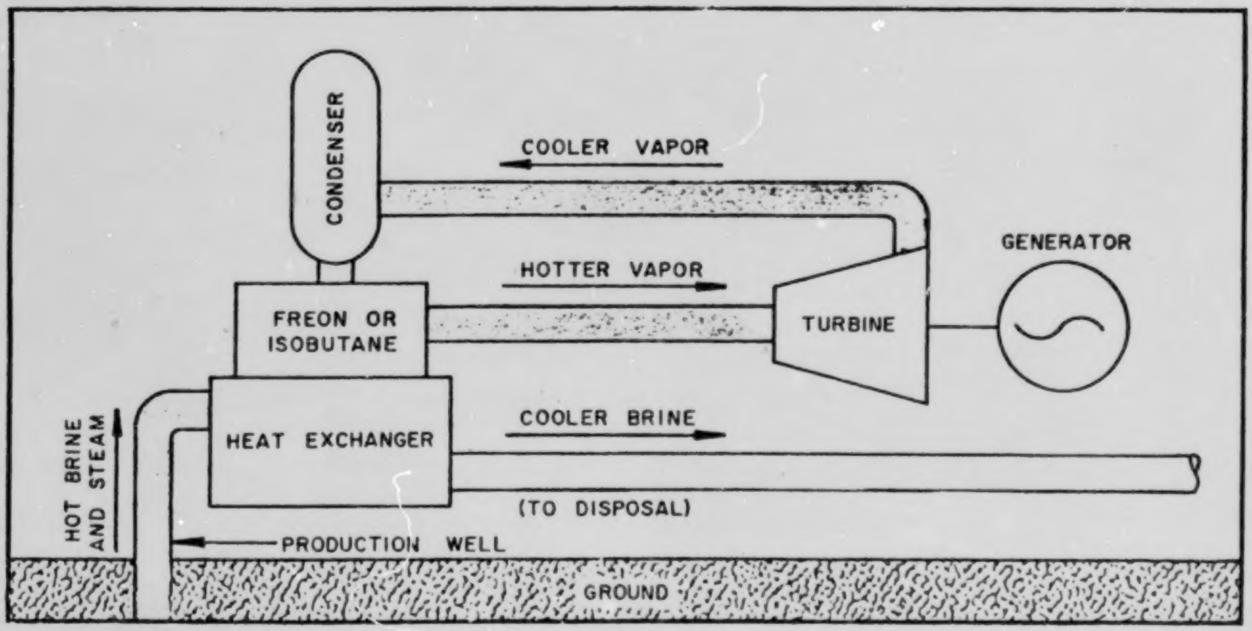
Figure 12-5


COOLANT WATER
GENERATOR
STEAM
TURBINE
EXHAUST STEAM
CONDENSER
COOLANT AND CONDENSATE
SEPARATOR
BRINE
(TO DISPOSAL)
HOT BRINE AND STEAM
(TO DESALTER, DISPOSAL, OR INJECTION)
PRODUCTION WELL
GROUND

FROM WATER-DOMINATED RESOURCE: OPEN METHOD

POWER FROM GEOTHERMAL RESOURCES

Figure 12-6


CONDENSER
COOLER VAPOR
GENERATOR
HOTTER VAPOR
FREON OR ISOBUTANE
TURBINE
COOLER BRINE
HEAT EXCHANGER
HOT BRINE AND STEAM
(TO DISPOSAL)
PRODUCTION WELL
GROUND

FROM WATER-DOMINATED RESOURCE: CLOSED METHOD

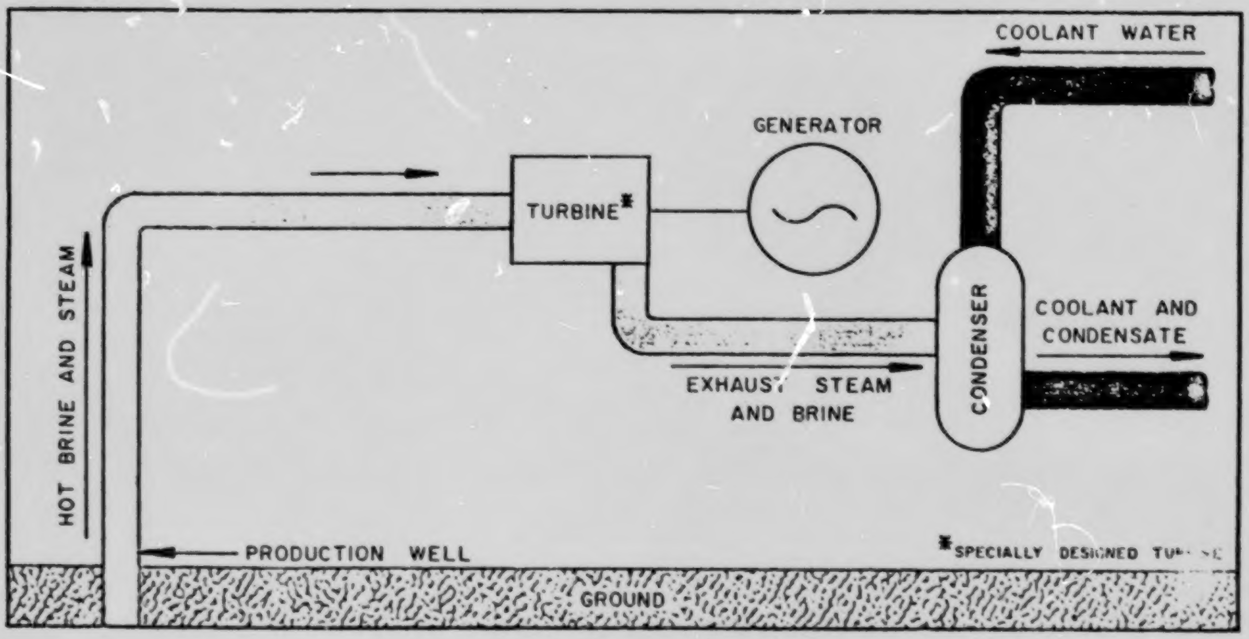
At an 80°F. condensing temperature, the specific volume of steam is 633 cubic feet per pound, whereas that of isobutane at the same temperature is 1.68 cubic feet per pound. With the physical size of turbines directly related to cost, it is apparent that a much smaller unit employing isobutane could be utilized for a given power output.

As an alternative to the two methods cited, researchers at the Lawrence Livermore Laboratory have proposed that all materials pumped from hot water reservoirs be used directly in a specially designed turbine. This equipment would eliminate the need for the steam separator when brine is flashed to steam or the heat exchanger in a closed fluid method. Instead, the entire flow would be routed directly from well to turbine. The exhaust steam and brine leaving the turbine would be passed through a condenser for cooling and discharge. (See Figure 12-7)

Environmental Aspects and Use

Geothermal units do possess some adverse environmental consequences, but most experts consider these to be more easily managed than those associated with fossil - and nuclear-fueled power plants. One could argue that a 1,000-megawatt plant utilizing hot water typical of the Imperial Valley would produce approximately 12,000 tons of salt per day. In absolute fairness, one would also have to state that since the materials could be reinjected, no adverse environmental impact would result. However, at reduced temperatures, some salts would come out of solution and it may be difficult to reinject these as suspended solids without plugging the reinjection wells.

Figure 12-7


COOLANT WATER
GENERATOR
TURBINE*
HOT BRINE AND STEAM
CONDENSER
COOLANT AND CONDENSATE
EXHAUST STEAM AND BRINE
PRODUCTION WELL
*SPECIALLY DESIGNED TU
GROUND

FROM WATER-DOMINATED RESOURCE: TOTAL MASS METHOD

Of the hydrogen sulfide brought to the surface by dry steam at the Geysers, some 30% is oxidized or reinjected. Research indicates that through chemical treatment, he percentage lost to the atmosphere can and is being reduced to acceptable limits.

Geothermal fluids also generally contain minute quantities of radon 222, one of the products of the decay chain of radium. The alpha radiation level monitored at the Geysers discloses about 0.015 x 10^7 microcuries/milliliter, a figure significantly below public health standards for drinking water.

An examination of the 60-year environmental history of the geothermal field at Larderello, Italy, seems to argue strongly that geothermal energy is a "good neighbor" form of energy. Except for the area directly beneath the steam lines, the terrain is used for both tree and vineyard crops. There's no reason that similar land uses of the majority of the area within the geothermal field at the Geysers could not be achieved.

Economic Considerations

A major advantage of geothermal energy is the lower capital costs involved in power plant construction. There is none of the equipment normally needed for handling natural gas or oil, i.e., gas or oil lines, pumps and/or storage equipment. Also eliminated are the major costs associated with construction, operation and maintenance of boilers for steam production. The primary cost, then, relates to steam collection and control and energy conversion equipment, i.e., turbines and generators. The cost of steam to the Pacific Gas & Electric Company for the Geysers generating units is tied to a formula which considers the costs of natural gas, petroleum and nuclear fuels. Exploration and delivery of the steam are managed by private companies acting independently of the public utility.

Modern geothermal units at the Geysers represent a construction cost per kilowatt of $250, compared to $600+ for a nuclear facility. In addition to being the least capital intensive of any of the existing energy conversion systems, geothermal units, much the same as hydro units, are easily adapted to automatic and radio control devices.

The Future Role of Geothermal Power

Estimating the future role of geothermal energy in power production is not unlike picking one horse in a close race. While estimates of the resource potential of geothermal energy are impressively large, little agreement exists as to what portion may be used beneficially.

R. W. Rex, previously associated with the geothermal resources program at the University of California, Riverside, has estimated that 400,000 megawatts of capacity, with a projected life of a century, could be discovered and developed in the western U.S. within 20 years. This assumes that individual geothermal reservoirs are managed to last for 100 years, with reservoir pressure maintenance and water injection programs used as needed.

Within California, Rex has located some eight areas in the Imperial Valley with an estimated potential of 20,000 megawatts of generating capacity. Estimates for the field capacity of the Geysers range from 1,000 to 4,000 megawatts; estimates of the U.S. potential for geothermal electrical energy vary from .5% of our projected electrical needs to complete servicing of U.S. electrical demand.

It is apparent from the range of estimates that reasonable men can and do differ about geothermal energy.

CHAPTER 13

SOLAR ENERGY

Hard economic facts notwithstanding, millions of Americans seem prepared to accept solar energy as a "free good" which is inexhaustible, environmentally pure and blessedly independent of oil companies, utilities and other energy organizations. It is none of these, but it is a promising hole card against the ultimate depletion of fossil fuels.

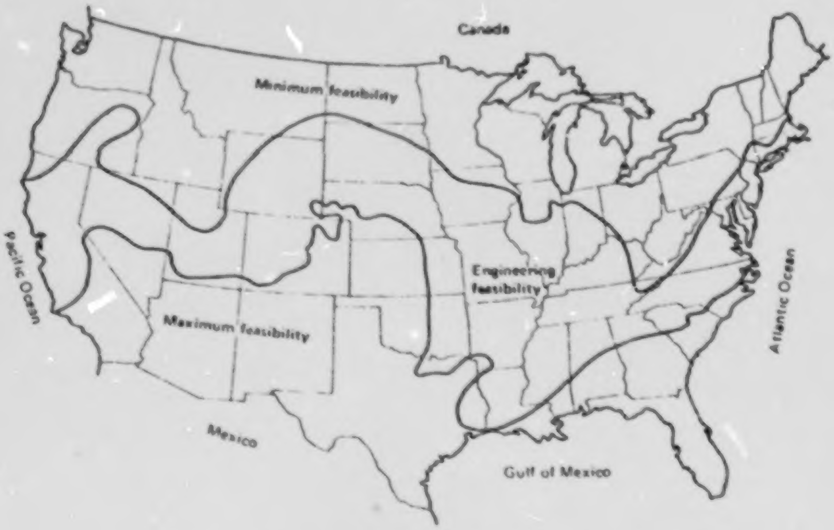
In contrast to the short-term availability of fossil fuels, solar energy is both constant and dependable over any time dimension reasonably imaginable. Outside the earth's atmosphere, insulation approaches 1400 watts per square meter. About 10% of this eventually reaches the earth's surface.

Maximum solar intensity under ideal conditions at the earth's surface equals approximately 1.2 watts per square meter. If one uses an average value of 10% conversion efficiency, it becomes apparent that about 1,000 sq. meters would be required to illuminate a 100-watt light bulb. (See Figure 13-1 and 13-2)

If the solar power is converted at only 1% efficiency, the output would exceed the present power output of all the electric utilities in the U.S. Of course, dedication of that much land to solar generation represents a practical approach subject to debate.

Solar energy reaching the earth is so extremely dilute, i.e., widely dispersed, that very extensive collection areas must be employed. Also, solar energy is intermittent on both a daily and an annual basis. Peak periods of electricity use, nationwide, occur during the evening periods and in some areas, during the winter, the very times when solar energy is least available. This means that storage or backup systems must be provided to supply energy when solar is unavailable.

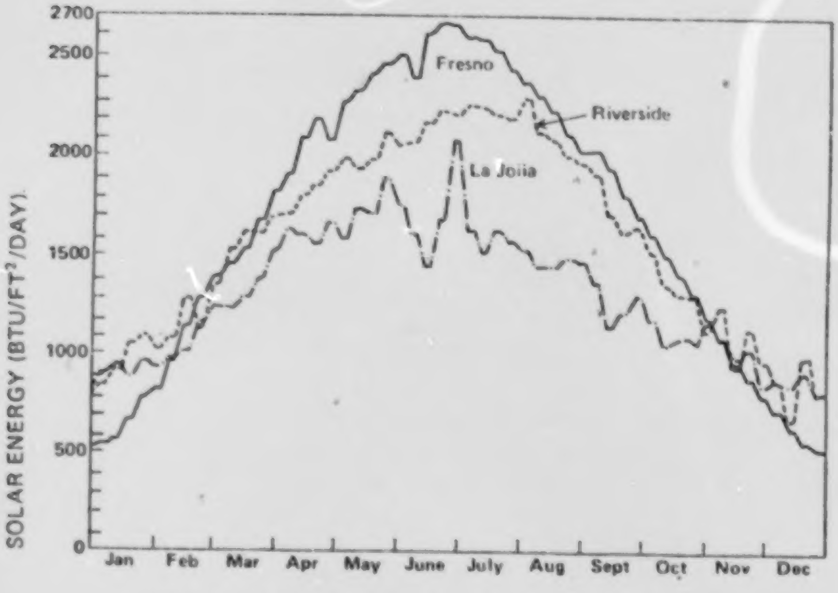
Figure 13-1


Canada
Minimum feasibility
Engineering feasibility
Maximum feasibility
Pacific Ocean
Atlantic Ocean
Mexico
Gulf of Mexico

Feasibility of Solar Heating Systems in the Conterminous United States

Redrawn from "Climatic Considerations of Solar Energy for Space Heating: Abstract of a Paper Presented at the Solar Energy Symposium" by T. A. Siple, M.I.T., Aug. 21, 1950 as published in *Energy in the Future* by P. C. Putnam, p. 180. Copyright assigned by D. Van Nostrand Company, Inc., to the General Manager of the Atomic Energy Commission.

Figure 13-2



Monthly Variation of Incident Solar Energy, California

Redrawn with permission from *Introduction to the Utilization of Solar Energy* by A. M. Zarem and Duane D. Erway, eds. (New York: McGraw-Hill Book Company, Inc., 1963), p. 35.

The practical significance of this is that homes utilizing solar heating must include a backup system as well, a fact which can substantially alter solar economics.

A third disadvantage, one which may give way to research and technological improvements, is the capital intensiveness of solar systems. With regard to large-scale application of solar energy, no technological breakthroughs are required. The major problem today is one of economic feasibility. And this should ease as petroleum, natural gas and other fuels become more expensive. (See Table 13-1)

Uses: Present and Proposed

Perhaps the earliest recorded use of solar power was to dry foods. Researchers at the University of California, Davis, and Cal Poly, San Luis Obispo, today seem poised to rediscover this ancient technology. Evaporation of water to obtain salt also dates back for centuries. The south part of the San Francisco Bay contains thousands of acres of ponds used to produce salt by evaporation. The area is the largest such natural salt-producing area in the world.

Solar water heating, which requires relatively small collecting surfaces and only the addition of insulated storage tanks and pipes for water circulation, is a technique long understood and practiced. Maintenance is minimal, and it is possible to achieve temperatures approaching the boiling point. Most students are familiar with the technique of utilizing a piece of plastic and a container to provide drinking water through solar distillation. This secret has been known to residents of many of the world's desert regions for over 100 years.

Table 13-1

Costs of Space Heating (1970 Prices) In Dollars Per Million Btu Useful Delivery[*]

Location	*Optimized solar heating cost in 25,000 Btu/degree-day house, capital charges @ 6%, 20 years*		*Electric heating, usage 30,000 kw-hr/year*	*Fuel heating fuel cost Only*	
	Collector @ \$2/ft²	*Collector @ \$4/ft²*		*Gas*	*Oil*
Santa Maria	1.10	1.59	4.28[†]	1.52	1.91
Albuquerque	1.60	2.32	4.63	0.95	2.44
Phoenix	2.05	3.09	5.07	0.85	1.89
Omaha	2.45	2.98	3.25[§]	1.12	1.56
Boston	2.50	3.02	5.25	1.85	2.08
Charleston	2.55	3.56	4.22	1.03	1.83
Seattle-Tacoma	2.60	3.82	2.29[‡,§]	1.96	2.36
Miami	4.05	4.64	4.87	3.01	2.04

[*] Source: NSF/NASA Solar Energy Panel, "Solar Energy as a National Energy Resource," (Washington, D.C.: National Science Foundation, 1972).

[†] Electric power costs are for Santa Barbara; electric power data for Santa Maria were not available.

[‡] Electric power costs are for Seattle.

[§] Publicly owned utility.

Solar heat costs are from optimal design systems yielding least cost heat.

Since 1973 and the oil embargo, our own nation has witnessed an unprecedented awakening of interest in utilizing solar energy for space heating and cooling, for heating domestic water and for heating swimming pools. Regrettably, development of domestic-sized electrical generation units has been restricted by technological barriers, as well as high capital costs.

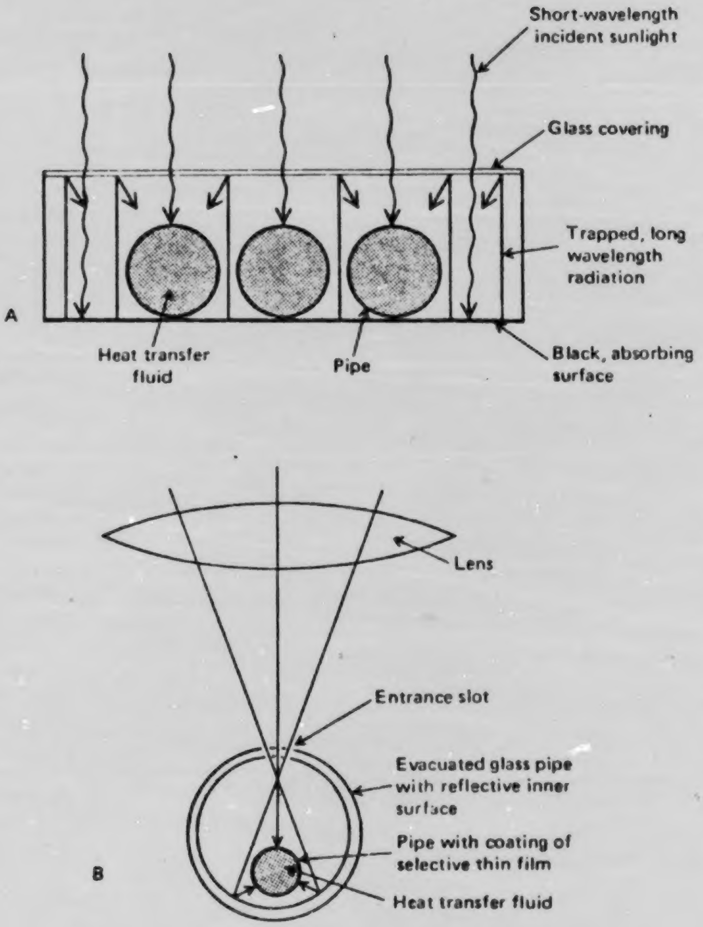
Technologies For Use

Solar energy may be concentrated via reflectors or collection devices and used directly; in this sense, it remains essentially unchanged. More recently developed technology allows the conversion of solar energy into electrical energy through the use of solar, or photovoltaic, cells.

As a point of reference, it should be noted that about 55% of the energy used in residential and commercial establishments is for space hearing. If solar energy could contribute a substantial fraction of this, significant energy savings would certainly result. A number of solar-heated homes have been constructed in California and other parts of the western U.S. with varying success. Experimental, and relatively unsophisticated, the prototypes do serve to provide a data base from which extrapolations concerning future uses can be made.

The collectors developed to date have typically been of the fixed orientation, low-temperature type, are south-facing units and are usually inclined, or "pitched," 45 to 60 degrees above horizontal. Flat-plate energy collectors consist of a series of pipes, usually of metal (in some cases plastic), attached to a flat surface. The pipes and the surface of the collector plates are painted dull black to absorb as much radiant energy as possible. (See Figure 13-3 and 13-4)

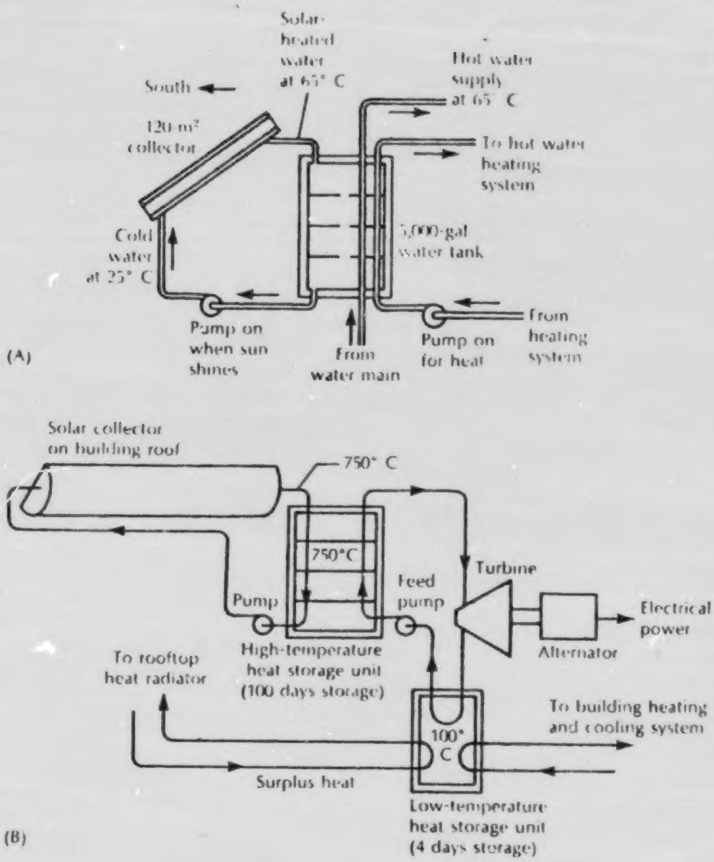
Figure 13-3


Short-wavelength incident sunlight
Glass covering
Trapped, long wavelength radiation
A
Heat transfer fluid
Pipe
Black, absorbing surface
Lens
Entrance slot
Evacuated glass pipe with reflective inner surface
Pipe with coating of selective thin film
B
Heat transfer fluid

Collector Systems for Converting Sunlight into Heat

Modified with permission from "Physics Looks at Solar Energy" by Aden Baker and Marjorie Pettit Meinel in *Physics Today* (Feb. 1972): Fig. 6, p. 49. Reprinted with permission from the American Institute of Physics, Inc.

Figure 13-4


Solar-heated water at 65° C
South
Hot water supply at 65° C
120-m² collector
To hot water heating system
Cold water at 25° C
5,000-gal water tank
Pump on when sun shines
From water main
Pump on for heat
From heating system
(A)
Solar collector on building roof
750° C
750°C
Turbine
Pump
Feed pump
Electrical power
Alternator
To rooftop heat radiator
High-temperature heat storage unit (100 days storage)
To building heating and cooling system
100° C
Surplus heat
Low-temperature heat storage unit (4 days storage)
(B)

(A) The simplest solar energy systems are those designed for domestic space and hot water heating. In such systems, an inclined, southerly-facing flat-collector is typically coupled with a heat storage system from which heat can be drawn when required. This diagram shows a combination system that provides domestic hot water at 65°C and hot water, as well, for space heating. (B) This solar-powered total-energy system is projected for use in suburban shopping centers or industrial plants where space for solar collection is available. One-axis-steerable concentrators would be situated on the roof; high-pressure dry nitrogen, steam, or sodium chloride would transfer heat at 750°C to a high-temperature storage unit of insulated rocks or molten salt. Heat drawn from the storage unit would drive a turbine to produce electrical power and then, held in a low-temperature storage unit, would be available for space heating or air conditioning.
(From Morrow, 1973.)

Glass panes (sometimes plastic sheets) cover the collector a few inches above the surface. Most collectors have flat lower surfaces, but some experimental versions have corrugated surfaces layered with a reflective material to help concentrate the solar energy.

Under ideal conditions from 80% to 95% of the solar energy available to the collector can be absorbed. Losses are a function of working temperature, re-radiation, convection and conduction (good design can minimize convection and conduction losses).

Since sunshine is unavailable about half the time, solar systems require heat storage units. Heat storage utilizes a variety of media -- water, rocks or gravel, and in some of the more sophisticated designs, liquid salts.

In designing a solar heating system for a home, the first step is to determine what percentage of annual heating needs the system will be expected to deliver. This decision is a matter not only of economics, but also of aesthetics; most home-owners prefer to have as little roof area as possible covered by collectors.

Solar heating imposes economic parameters, too. Even with considerable year-around insolation, supplemental heat sources will likely be required. The final decision on the size and performance of the system, then, will be based largely on cost.

Experience with homes in the East suggests that 50% of the heating is a reasonable objective. Homes in the southwestern U.S. or Southern California will likely realize a larger solar output with equivalent systems. Savings on utility bills can be estimated by calculating the anticipated share of the heat load assigned to solar and deducting that from the monthly bills.

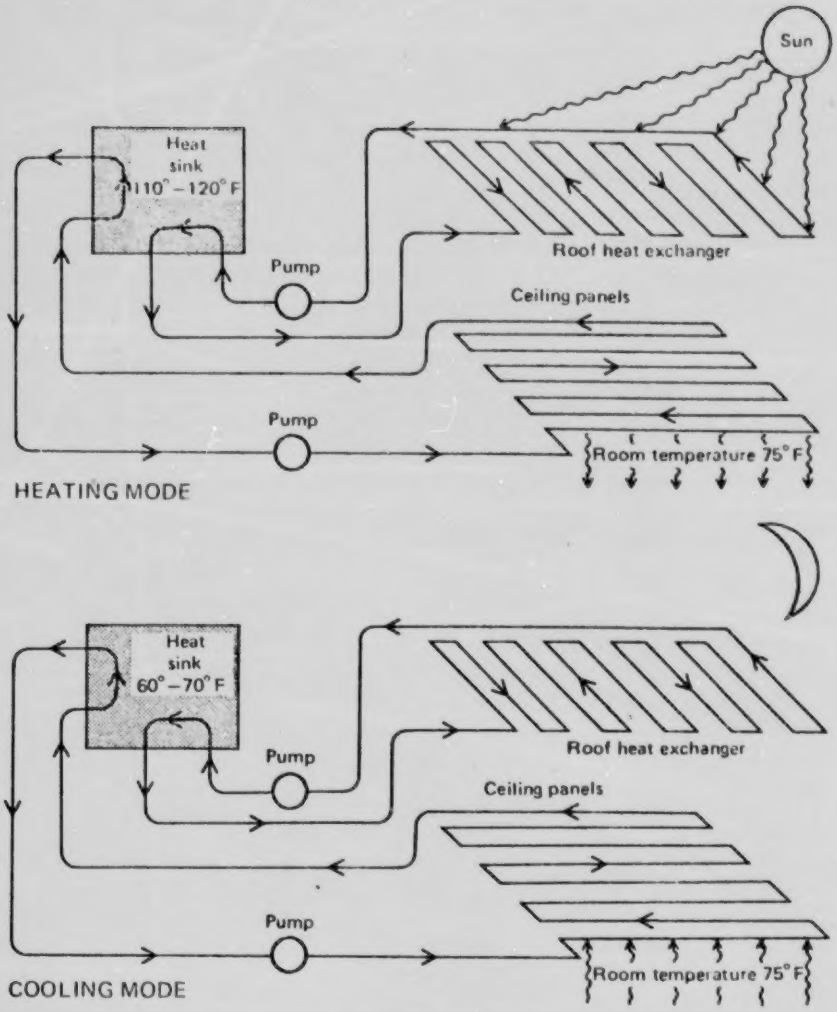
Let's now consider an apparent contradiction; achieving cooling as a function of heating. Using solar energy for cooling (or refrigeration) has considerable appeal, because the need for cooling exists to the greatest extent in those areas and/or countries with the hottest climates and most days of sunshine. (See Figure 13-5, 13-6, & 13-7)

It is important to distinguish between solar cooling and solar air conditioning. Solar cooling works on the principle of radiative cooling and can be incorporated into the typical solar heating system. The cooling cycle utilizes the collectors to radiate accumulated heat during the cool evening hours. The role of the storage unit is reversed, with cold water from the storage area being distributed through the home during the hotter periods of the day.

Solar air-conditioning functions in very much the same fashion as a household refrigerator. In a conventional air-conditioning or refrigeration system, cooling is achieved through the expansion of a gas such as freon which absorbs heat as it expands. In a solar air-conditing unit, the heat energy is used to separate ammonia from an ammonia-water solution. The ammonia is collected, condensed and stored in a separate container. When cooling is required, the ammonia is evaporated and as it expands, it absorbs heat in the same manner as inert freon in a conventional household refrigerator.

The primary disadvantage of solar-driven refrigeration systems is that temperatures above 120°C. are required for efficient operation. Since temperatures exceeding the boiling point of water are not achieved in the typical flat plate-solar collector, concentrated collection is required. This is theoretically achieved by telescoping solar energy from a relatively large area into a smaller area.

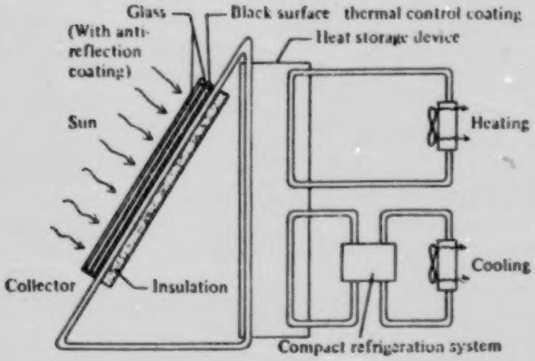
Figure 13-5


Sun
Heat sink 110° – 120° F
Pump
Roof heat exchanger
Ceiling panels
Pump
Room temperature 75° F
HEATING MODE
Heat sink 60° – 70° F
Pump
Roof heat exchanger
Ceiling panels
Pump
Room temperature 75° F
COOLING MODE

Storage of Thermal Energy from the Sun

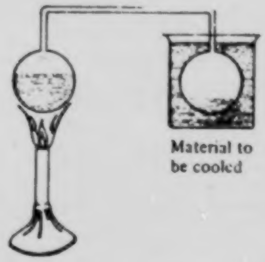
Modified with permission from *Introduction to the Utilization of Solar Energy* by A. M. Zarem and Duane D. Erway, eds. (New York: McGraw-Hill Book Company, Inc., 1963), p. 277.

Figure 13-6


Glass
(With anti-reflection coating)
Black surface thermal control coating
Heat storage device
Sun
Heating
Cooling
Collector
Insulation
Compact refrigeration system

The most simple solar collecting device would use a blackened flat plate with a transparent, antireflection coating. Circulating water removes the heat for storage or use. (Source: "Solar Energy Research," *op. cit.*)

Figure 13-7


Material to be cooled

The absorption cooling process. Ammonia vapor driven out of solution in A by heat is condensed in B. If A is now cooled, the vapor will be reabsorbed in A and take heat energy from the medium surrounding B.

The difference between "focused" and "unfocused" solar energy collectors are indeed striking. Unfocused collectors typically have concentration-to-emissivity (radiation) ratios approaching 10 and are limited to output temperatures below 150°C. Focused collectors demonstrate concentration-to-emmissivity ratios of nearly 300 and achieve temperatures nearing 600°C.

The use of solar energy for air-conditioning, heating and other applications deserves continued research and development. Only in this way, and through broader educational efforts, can we encourage broader application of solar energy in meeting a greater part of a nation's energy requirements.

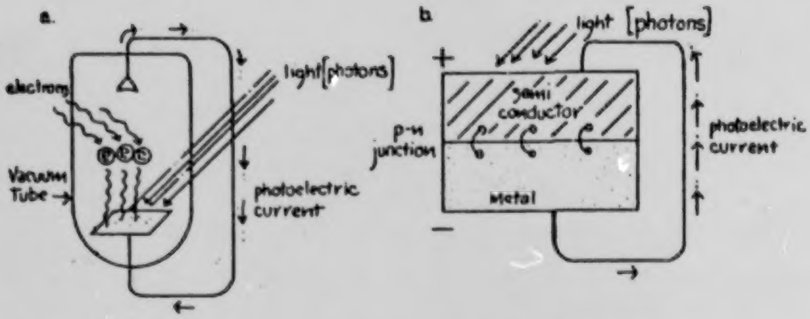
Solar cells convert sunlight directly into electricity. They became widely known through their key role during Apollo space flights and are regarded by some as the electrical energy source of the future. (See Figure 13-8)

At the present time, solar cells cannot compete economically as a means of providing electrical energy, nor are they likely to on the basis of existing or proposed technology.

The term, "solar cell," is applied to a variety of energy-converting devices but generally refers to a device that produces an electric current when activated by light. The physics of these devices is complex, but, basically, solar cells develop an electrical potential similar to that demonstrated in the ordinary flashlight battery.

Instead of chemical energy, however, solar cells (more properly, photovoltaic cells) use "photoelectric effect" to develop the electrical potential. A number of elements, potassium, for example, lose some of their more loosely bound outer shell electrons when struck by cosmic particles called photons. If the energy gain is sufficient for the electron to escape the magnetic field set up by the photons, and if a circuit exists, a minute electric current will flow within the system.

Figure 13-8



~~Figure 9-6~~. Functional diagrams of two types of photovoltaic cells. The semiconductor type is often called a solar cell.

The name solar cell is imprecisely applied to a variety of energy converting devices. It is occasionally applied to any device that produces electricity from solar heat; but most often it refers to one that produces an electric current when light falls on it. The proper name for such a solar cell is a photovoltaic cell, and it is based on a phenomenon known as the photoelectric effect. Many metals and some non-metals exhibit this effect. When light strikes atoms of such a substance, energy is imparted to the outer, most loosely bound electrons. If the energy is sufficient to drive the electrons away from the atoms, and if a suitable collector is connected in a circuit with the electron-emitting substance, an electric current will flow. Devices like that pictured in figure 9-5, a have long been used in a variety of ways (for example, as photo cells in door openers and light meters). Their requirement for a vacuum tube makes them unpromising for large-scale energy conversion.

Semiconductors (primarily silicon crystals) may exhibit photoelectric effects when formed in a p-n junction unit with a metal or another semiconductor (figure 9-5, b). These cells are used as solar converters on many satellites and are sometimes proposed for large-scale conversion of solar energy. Silicon cells are unpromising because it is difficult and expensive to grow large single crystals. Innovations in thin film solar cells using cadmium sulfide should reduce the cost greatly, but fundamental problems remain.

The root of the problems is explained by an equation of Einstein's describing the energy balance in photoelectric conversion: $hc/\lambda = W + \frac{1}{2}m_e v^2$, *where* h *is Planck's constant,* c *is the velocity of light, and* λ *is the wavelength of radiation.* W *is the energy required to eject an electron from the substance,* m_e *is the mass of the electron, and* v *is its velocity in a vacuum.* W, *the photoelectric work function, has a characteristic value for each*

Although variations in potential exist with different elements, a single solar cell of silicon dioxide has an electric potential of about 0.6 volts. The electrical capacity and potential of solar cell assemblies can be varied by the way the cells are connected, either in parallel or series. Unfortunately, the materials known to respond to photon activation are affected by a very narrow component of the total solar spectrum. Consequently, the effiency of solar cells remains low, somewhere between 10 and 14%.

Public acceptance of solar cells in the space program is no doubt quite a different animal than acceptance by utilities or in home appliance use where unit costs are crucial. Solar cells must realize quantum reductions in cost if they are to become generally accepted. Costs for a large-scale silicon cell installation, using existing technology, could run as high as $100,000 per kilowatt of capacity.

A number of factors are responsible for the high cost of solar cells. Molten silicon is a highly reactive and unstable substance which tends to absorb impurities, a characteristic which drastically reduces cell reliability. Cells made of cadmium sulfide appear to hold promise for low-cost photovoltaic needs but at a substantial reduction in efficiency, about 6%.

A primary advantage of the cadmium sulfide material is that it can be made into thin microcrystalline film which appears to lend itself to mass production. This advantage is offset in part by a lack of reliability. The cells tend to degrade in the presence of moisture, higher temperatures and intense illumination. Gallium arsenide cells are radiation resistant and have efficiencies of about 18%. But gallium is scarce and expensive, leading to high production costs.

One must recognize that solar cell research is relatively new and that it has been slowed by lack of funds. It appears that in the immediate future solar cell uses will be limited to special applications where high unit costs can be justified.

Solar cell power plants mounted on synchronous satellites have been proposed by Peter E. Glaser of Arthur D. Little, Inc. The system proposed would not be affected by clouds, and the orbit proposed is such that the system would receive continuous sunlight except for two 6-week periods per year when earth shadowing would occur for about 1 hour. The proposal is to use photovoltaic cells to produce DC current which would then be converted to radio energy at the microwave frequency of 3,000 MH_z for transmission to the earth.

All components of the system would be massive by any scale with which we are familiar: the satellite-mounted transmitter would be 1.4 sq. kilometers, and the receiving antennae on earth would cover 100 sq. kilometers. The satellite would carry an array of solar cells about 7 kilometers square, yielding an output power of 10^7 kilowatts. It is obvious that substantial reductions in cell and satellite launch costs would be necessary if this proposal were to be taken seriously.

Environmental Effects

"Energy in the Future," an American Association for the Advancement of Science booklet published in 1973, offers a lucid and succinct summation of solar energy effects. It merits quoting at length.

> "Potential environmental problems are probably fewer for solar energy than for any other major sources of energy, but they do exist. Collecting surfaces absorb more sunlight than the earth does, and while small-scale use is not likely to alter the local thermal balance, the large expanse of collecting surface in the central power plant might. Thermal pollution will also be a problem if water-cooled turbines are used -- indeed, more so than with nuclear plants because solar installations are expected to have even lower thermal efficiencies. If waste heat is returned to the atmosphere, it could help to restore the local thermal balance. The effects of small changes in the thermal balance would depend on the local meteorological conditions but are expected to be small. Because of the lack of particulate emissions and radiation hazards, solar-thermal power plants might be built close enough to towns or industrial sites so that their waste could be put to use. Finally, like other industrial facilities, large-scale plants carry some risk of accident with the attendance possibility of leaking corrosive heat transfer or storage media into the environment."

Space heating and cooling with solar energy are not available today. Solar thermal power plants have yet to be built on any but the smallest scale, and key elements of the necessary technology have not been adequately demonstrated. But both options appear to be close enough to a practical test of the economic viability to warrant increased effort.

Failure to consider the net energy potential of solar systems would be irresponsible. Enthusiasm is understandable, but blind advocacy on the basis of "chic" or sheer faith does nothing to advance the energy welfare of the nation. Now is the time for cold-blooded and objective analysis.

CHAPTER 14

WIND POWER - ORGANIC WASTE - OCEANS

Early Uses

The use of wind to drive vertical-axis machines traces back to about 900 to 1,000 A.D. By the late 1800's, thousands of windmills dotted the landscapes of the Scandinavian and European countries, as well as the U.S. As coal and fossil fuels gained acceptance in the 19th and 20th Centuries, the use of wind power declined rapidly.

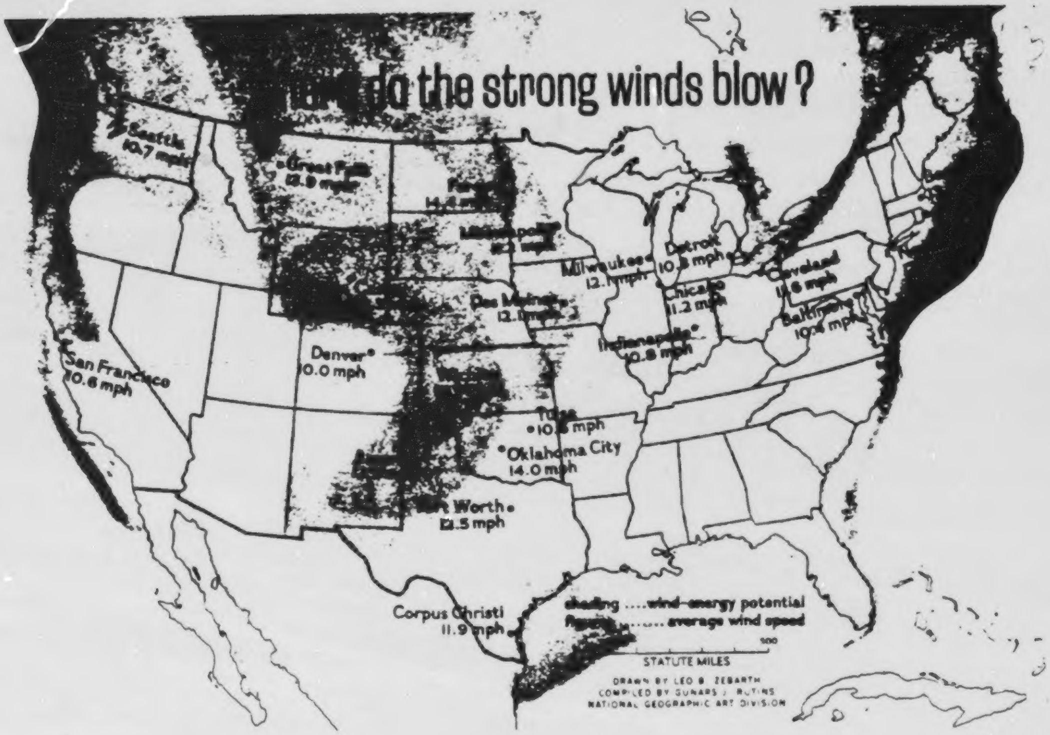
At the present time, wind makes only a minor contribution to the energy needs of most of the developed countries of the world. Wind-driven water pumps for livestock and domestic uses have all but disappeared from the scene in California and other western states. Even so, the energy dilemma has ushered in renewed interest in wind power as a possible alternative for conventional sources of electrical energy. (See Figure 14-1)

Wind as a Source of Power

No advocate of wind energy is more enthusiastic than Dr. William Heronemus, professor of Civil Engineering, University of Massachusetts. He is personally responsible for much of the understanding we have of wind and its energy potential. Students should certainly take advantage of the many articles written by Professor Heronemus or based on his research.

The basic concept of harnessing the energy contained in wind is simplicity itself. The air possesses mass, and that mass in motion can be harnessed to convert its kinetic energy into useful mechanical energy. The theoretical energy yield of wind is a function of the cube of its speed.

Figure 14-1


do the strong winds blow?
Seattle 10.7 mph
Great Falls
Fargo
Minneapolis
Milwaukee 12.1 mph
Detroit 10.3 mph
Chicago 11.2 mph
Cleveland 11.6 mph
Des Moines 12.1 mph
Baltimore 10.4 mph
Indianapolis 10.8 mph
San Francisco 10.6 mph
Denver 10.0 mph
Tulsa 10.8 mph
Oklahoma City 14.0 mph
Fort Worth 12.5 mph
Corpus Christi 11.9 mph
shading ....wind-energy potential
figures .... average wind speed
300
STATUTE MILES
DRAWN BY LEO B. ZEBARTH
COMPILED BY GUNARS J. RUTINS
NATIONAL GEOGRAPHIC ART DIVISION

Based on hourly observations by the National Weather Service over a ten-year period, this chart shows the average mile-per-hour wind speeds for several U.S. metropolitan areas.

Fargo, North Dakota	**14.4**
Wichita, Kansas	**13.7**
Boston, Massachusetts	**13.3**
New York, New York	**12.9**
Ft. Worth, Texas	**12.5**
Des Moines, Iowa	**12.1**
Honolulu, Hawaii	**12.1**
Milwaukee, Wisconsin	**12.1**
Cleveland, Ohio	**11.6**
Chicago, Illinois	**11.2**
Minneapolis, Minnesota	**11.2**
Indianapolis, Indiana	**10.8**
Providence, Rhode Island	**10.7**
Seattle-Tacoma, Washington	**10.7**
San Francisco, California	**10.6**
Baltimore, Maryland	**10.4**
Detroit, Michigan	**10.3**
Denver, Colorado	**10.0**
Kansas City, Missouri	**9.8**
Atlanta, Georgia	**9.7**
Washington, D.C.	**9.7**
Philadelphia, Pennsylvania	**9.6**
Portland, Maine	**9.6**
New Orleans, Louisiana	**9.0**
Miami, Florida	**8.8**
Little Rock, Arkansas	**8.7**
Salt Lake City, Utah	**8.7**
Albuquerque, New Mexico	**8.6**
Tucson, Arizona	**8.1**
Birmingham, Alabama	**7.9**
Anchorage, Alaska	**6.8**
Los Angeles, California	**6.8**

A simple calculation using wind velocities of 3, 6, 9, 12 and 15 miles per hour demonstrates the rapid increase in power output of a wind generator as velocities increase. The theoretical efficiency limit for wind turbines is 59%. Operationally, windmills of good design have achieved 75% to 80% of that theoretical maximum. The equation for calculating the power developed by an ideal wind unit is: $\frac{16}{27} \cdot \frac{1}{8} PD^2V^3$. (D = diameter of the turbine blades; P = wind density, and; V = wind velocity.)

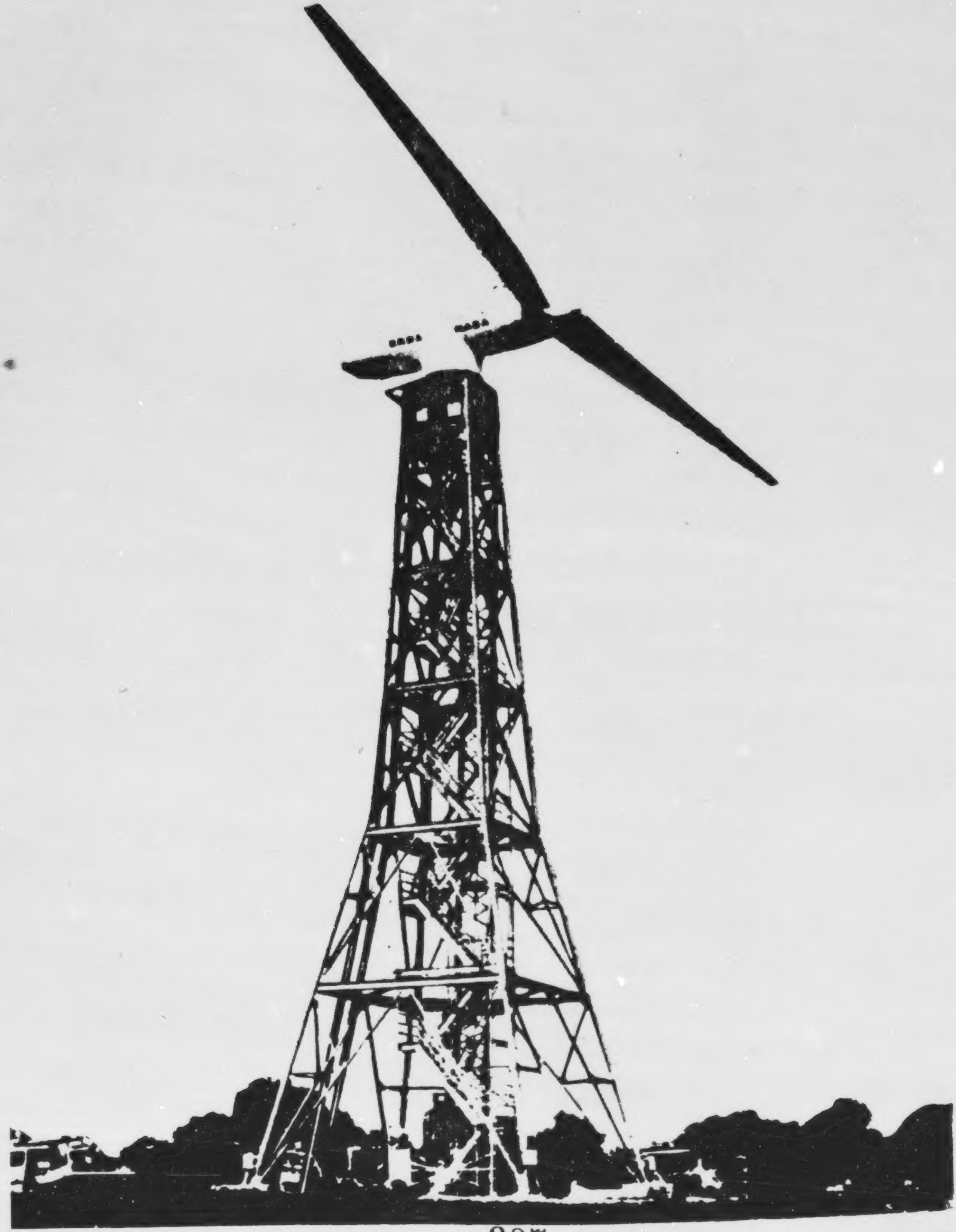
Disadvantages

One of the most frequently asked questions concerning the potential of wind power is: "What happens when the wind stops blowing?" The disadvantages of wind power are its diluteness, its variability, its tendency to occur in restricted geographical areas and aesthetic problems should large numbers of wind turbines be erected. With wind units, the only certain way to provide reliable electric power is by employing conventional nuclear, fossil or hydro backup systems.

From an engineering standpoint, impeller blades constructed of materials light enough to respond to the lighter breezes are likely to experience failures in high winds and under load stresses associated with snow and ice deposits. It is apparent that advances in aerodynamic design and engineering, as well as technology to improve energy storage will be necessary before wind energy can contribute significantly to U.S. energy needs. (See Figure 14-2)

Despite the deficiencies noted, several options appear worth pursuing. Foremost in terms of need is the development of batteries which can store the DC energy produced by wind generators. The costs of batteries associated

Figure 14-2



with large-scale wind systems are impressive. Some recent proposals for storing wind-generated electricity involve using the electricity to power air compressors, the product of which could be stored under pressure in large tanks, exhausted natural gas wells or depleted aquifers. The stored air could then be used to energize a gas or air turbine coupled to a generator. Alternatively, the wind-produced electricity could be used to electrolyze water, producing fuel hydrogen and oxygen. (See Figure 14-3 & 14-4)

Aesthetics of Wind Generators

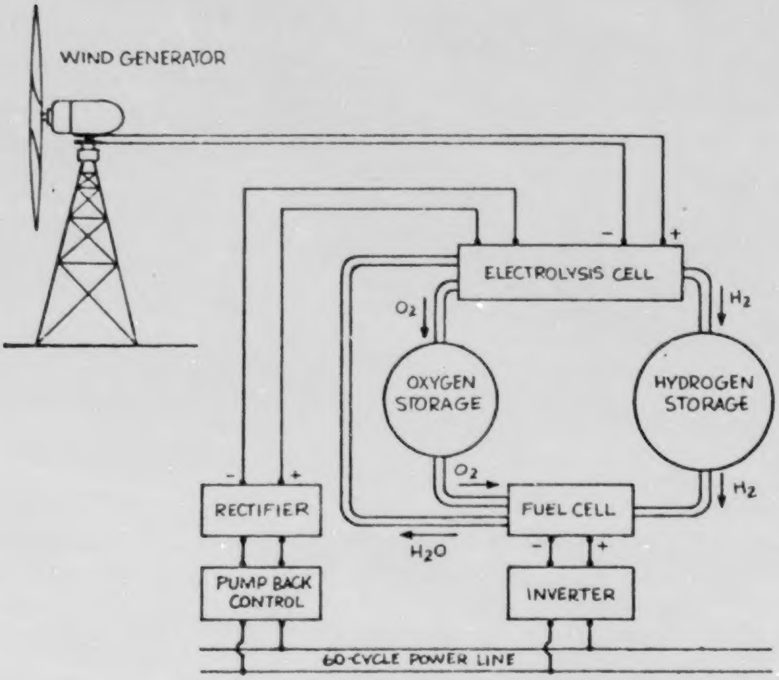
Construction of a few wind towers on farms or near homes might not offend large numbers of people. However, proposals for numerous wind turbines 600' to 800' in height, stretching for hundreds of miles across the Western prairie, could create unprecedented visual impact. Possible hazards - damage to birds, wildlife and aircraft -- would also have to be confronted.

One of the recommendations for eliminating the environmental impact of land-based chains of wind generators is to substitute armadas of floating "wind power" stations anchored in off-shore locations of known higher wind velocities. This proposal lacks appeal because of the remoteness of such systems from centers of consumption and the adverse visual impacts of the floating energy "islands." (See Figure 14-5)

Energy Conversion Technologies

The capability of a wind-turbine generator to produce electrical energy is a function of its aerodynamic shape, i.e., design, its location within the air mass, the capability of its blades to convert the kinetic energy of the

Figure 14-3


WIND GENERATOR
ELECTROLYSIS CELL
–
+
O_2
H_2
OXYGEN STORAGE
HYDROGEN STORAGE
O_2
H_2
FUEL CELL
H_2O
–
+
RECTIFIER
–
+
PUMP BACK CONTROL
INVERTER
60-CYCLE POWER LINE

Wind as Power Source. To harness wind effectively one must be able to store the energy captured when the wind blows and release it more or less continuously. One scheme would be to use the electricity gneerated by the wind to decompose water electrolytically. The stored hydrogen and oxygen could then be fed at a constant rate into a fuel cell, which would produce direct current. This would be converted into alternating current and fed into a power line. Off-peak power generated elsewhere could also be used to run the electrolysis cell whenever the wind was deficient. From C.N. Summers, "The Conversion of Energy," *Scientific American* (September 1971) p. 158.

Figure 14-4

Water can be separated into hydrogen and oxygen if an electric current flows through it. Note that the volume of hydrogen is twice that of oxygen because each water molecule contains two atoms of hydrogen and one of oxygen.

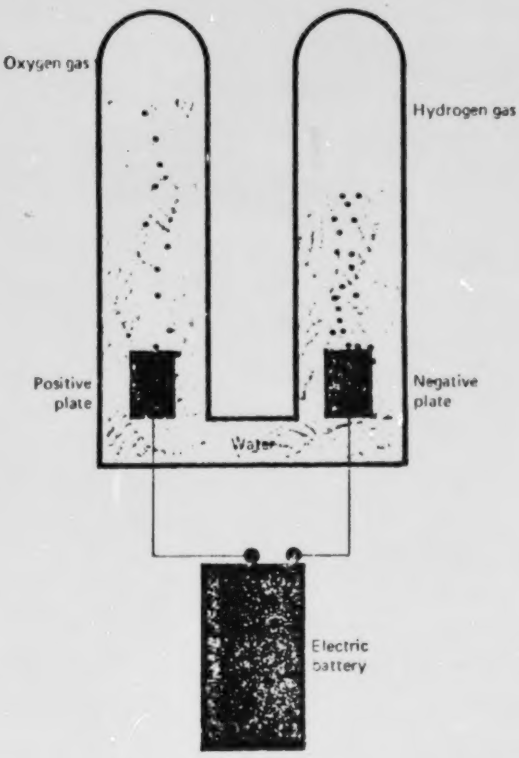
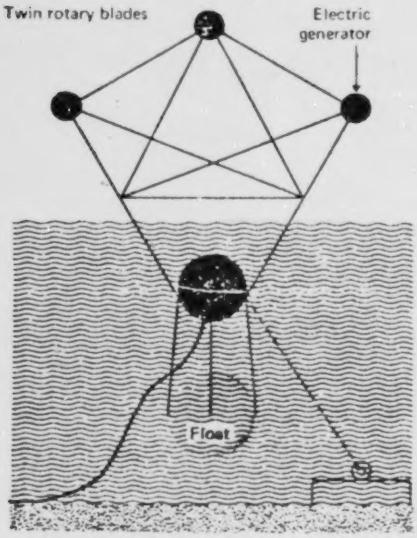

Oxygen gas
Hydrogen gas
Positive plate
Negative plate
Water
Electric battery

Figure 14-5

A conceptual drawing of a wind-powered electric generator located in the ocean.


Twin rotary blades
Electric generator
Float

wind to mechanical energy, and intelligent design factors which reduce to the absolute minimum the turbulence produced by passage of air through the rotors. A modern wind-powered generating unit consists of three components; a tower; the impeller and generator units, and; the distribution and storage facilities.

The challenge confronting tower designers is to make the units inexpensive, structurally resiliant and sufficiently tall to take advantage of wind speeds at higher elevations. One difficult aspect of the height/power ratio is that the taller the tower, the more expensive the unit.

Wind-driven generators and impellers, whether DC or AC, must be relatively maintenance-free, i.e., their expected production life must be from 10 to 15 years, and, because of remoteness, they must be free of troublesome, albeit routine maintenance problems. The impellers, or rotors, used to drive the turbine-generators represent sophisticated achievements in an engineering sense. Design calls for high rpm and low torque. The most efficient are the long tapered, 2- or 3- bladed high speed impellers with high-aspect ratios.

DC current carries with it some penalties not appreciated by the majority of persons. Household appliances such as refrigerators, freezers, television sets and radios cannot operate on DC current without extensive alteration or the use of DC-AC inverters.

In-depth analysis of the possible role of wind power, based on the economic imperatives of large-scale use, are limited because most of the projections are either conjectural or based on outdated assumptions. Capital costs may be far higher than is required for nuclear-fueled generating units, but operational costs, including maintenance, could prove to be low, barring that nemesis of wind systems, storm damage. Despite the enthusiasm of some for large-scale utilization of wind energy, its logical role seems to be to provide only a supplemental energy source.

In remote locations, it is possible that wind turbines could be the best choice as a source of electrical energy. However, that choice would largely be dictated by the comparative costs of more conventional systems such as gasoline or diesel generators. There is consensus that capital costs of wind turbines will decrease as the size of the units increases. This could prove important for utilities which may be evaluating wind turbines as peaking stations in remote areas; integrating such electric output into the utility grid is expected to be less expensive for large units.

POWER FROM WASTES

Americans dispose of about five pounds of solid waste apiece every day -- that's nearly a ton per year. Paper accounts for slightly more than one half of the total tonnage in municipal solid waste. Included here are newspapers, magazines, cardboard and brown paper. Food scraps and glass contribute 8%, ferrous and nonferrous metals, 7%, and organic materials such as rags and leather, 24%. Quantities of solid waste generated in this country each year are truly impressive, about 1.1 billion tons of inorganic wastes and more than 2 billion tons of organic waste.

An EPA study discloses that 52.7% of the "average" municipal solid waste is volatile material, 7.3% is fixed carbon, 20% is ash and metals and the remaining 20% is moisture. The combustible fraction of the waste, (volatiles and fixed carbon) make up 60% of the total weight and have an average heat content of 8,766 Btu's per pound. Overall, a typical pound of "processed" refuse contains 5,260 Btu. With a sulphur level of 0.12%, solid waste will produce only 0.23 pounds of sulphur per million Btu, quantities which easily meet latest federal emission standards for combustion units.

A 1971 study by L. L. Anderson, University of Utah, noted that the total volume of dry, ash-free organic waste produced in the U.S. was around 880 million tons a year. Of that, more than 80% was so widely dispersed that it could not be economically collected, leaving essentially 136 million tons of dry organic waste collectible for possible conversion to clean energy. This amount could produce 170 million barrels of oil, roughly 3% of total U.S. consumption of crude oil in 1971. If one considers "net energy" realities, contemplated use of organic wastes for power generation could prove to be a questionable proposal.

Traditionally, two basic methods have been utilized to dispose of wastes in our urban society. The simplest, and perhaps the oldest, is the use of pits, or cut-and-fill areas. The second method is burning, or incineration. Neither of these approaches is truly effective in disposing of waste; other than removing most of the material from sight, little has really been achieved.

Proposals to utilize wastes as a source of energy must recognize and deal with certain disadvantages:

1. Wastes are widely dispersed geographically;
2. Since noncombustible material makes up about half of the waste, energy yield is low;
3. Residues remaining after conversion pose a disposal problem;
4. Combustion of plastics can release poisonous gases which must be strictly controlled and;
5. Glass, char, cement and other inorganics in the waste stream still must be handled and disposed.

Many of the proposals in favor of waste conversion are simplistic in that most tend to ignore the difficulties associated with materials collection and conversion and of marketing low Btu fuels derived from waste, both gases and liquids. Too frequently, proponents of waste conversion overestimate the net energy yield by failing to factor in all of the energy components required for the transformation of refuse into useable energy forms.

Still, conversion of organic wastes into fuels can be a substantial improvement in the way we dispose of unwanted materials. The value of wastes as an energy resource will depend to a great extent on the development of programs which minimize energy costs in waste collection and emphasize using the energy in the waste itself for conversion.

In Europe, the use of waste materials as fuel is quite common. Germany has more installations than any other European country; those plants now process waste materials generated by some 11 million persons. In Milan, Italy, a trash-burning power unit has been developed which is designed to accommodate about 660 tons of refuse each day. In the European installations, refuse is generally burned in a separate boiler, with some form of fossil fuel used as a supplemental heat source.

The closest American counterpart to the Europeans is a system in Nashville, Tennessee. In 1974, the Nashville Thermal Transfer Corporation began burning solid wastes to produce energy for heating and cooling buildings. Steam and chilled water are produced and then piped to 27 buildings in downtown Nashville.

Designed for a daily input of some 720 tons of refuse, it was expected that the process would be expanded to accommodate the total refuse produced in metropolitan Nashville. The system was designed to save about $3 per ton on refuse collected, for an annual savings of more than $125 million dollars, however, costs have been much higher than anticipated and the project has failed to meet the quality criteria. Its future is clouded.

One of the most widely publicized projects in which refuse has been used as a fuel is that being conducted in the City of St. Louis, Missouri. In this, the waste is reduced in size to 1.5-inch chunks. Metallic and other noncombustible portions are then removed. The burnable material is trucked to the

Merrimac Power Plant of the Union Electric Company where it is mixed with coal (1 part waste to 4 parts coal) and fed into boilers.

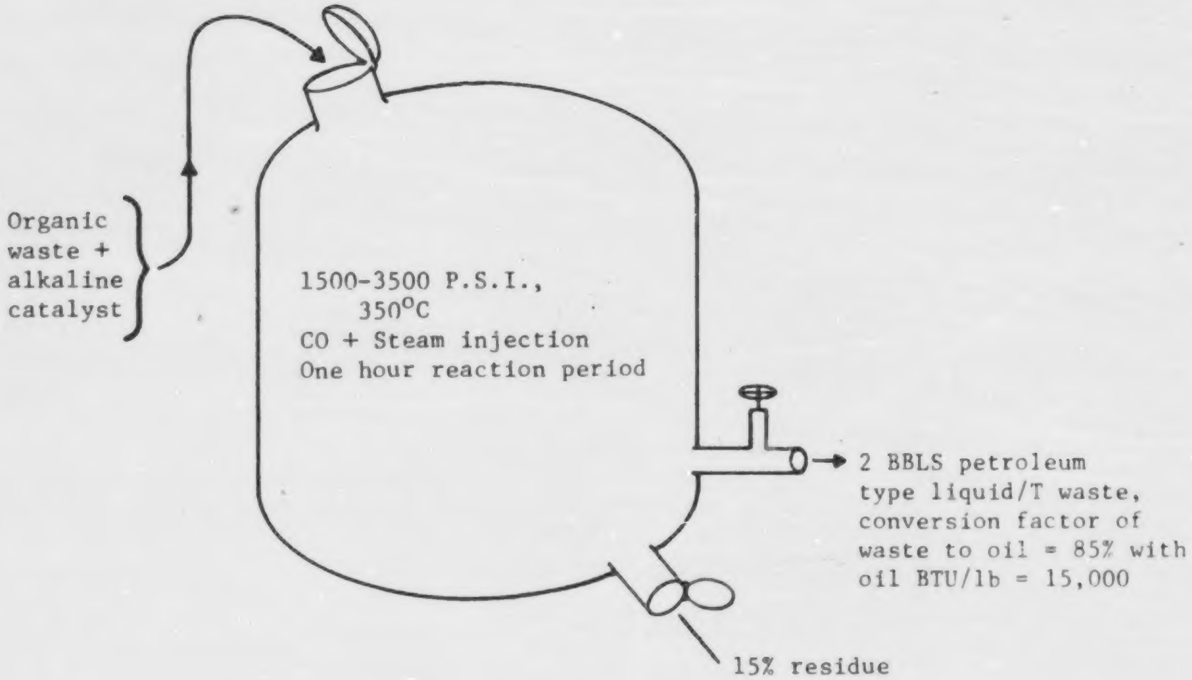
A large number of companies are involved in research on improving waste conversion efficiencies with a majority of the programs funded by federal and state agencies. Of the many approaches being considered, all fall into one of three categories: hydrogenation, pyrolysis, or bioconversion. Let's have a look at each. (See Figures 14-6, 14-7, 14-8)

A hydrogenation process, developed by H. R. Appell and I. Wender, Bureau of Mines Energy Research Center, has attracted much attention. A more appropriate term for the process might be "deoxygenation," because it basically involves the removal of oxygen from cellulose through the use of carbon monoxide and steam. As in pyrolysis and bioconversion, all organic wastes can be processed by the hydrogenation process.

In hydrogenation, the organic waste is mixed with an alkaline catalyst such as sodium carbonate and placed in a vessel in the presence of carbon monoxide and steam. It is then subjected to heating (240 to 380 degrees C.) for periods up to one hour at high pressures (100 to 250 atmospheres). Under ideal conditions, almost 100% of the carbon content of the waste would be converted to oil, with the average yield approaching two barrels per ton of waste.

The two barrels are not a net yield since slightly less than 50% of the oil is required to provide heat and CO for the reaction. Thus, the net yield for the hydrogenation process is a little more than one barrel of oil per ton of waste. The heavy parafinic oil contains about 15,000 Btu/lb., about 15 to 20% less than fuel oil.

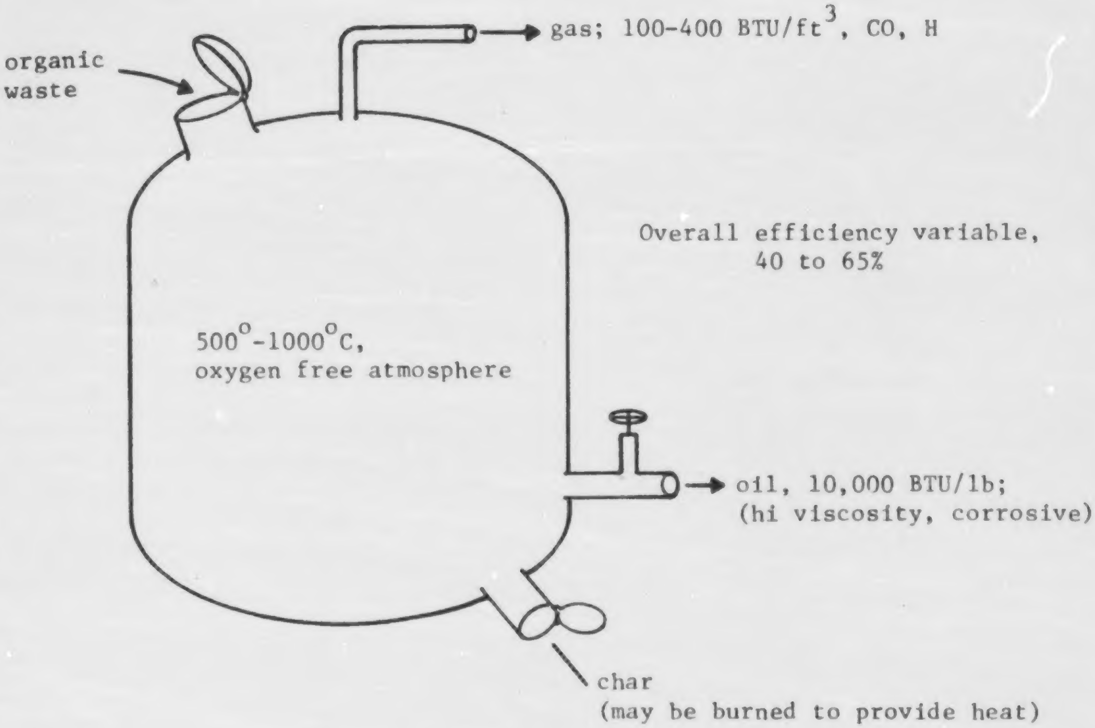
Figure 14-6


Organic waste + alkaline catalyst
1500-3500 P.S.I., 350°C
CO + Steam injection
One hour reaction period
2 BBLS petroleum type liquid/T waste, conversion factor of waste to oil = 85% with oil BTU/lb = 15,000
15% residue

HEATED, HIGH PRESSURE VESSEL

Hydrogenation (chemical reduction)

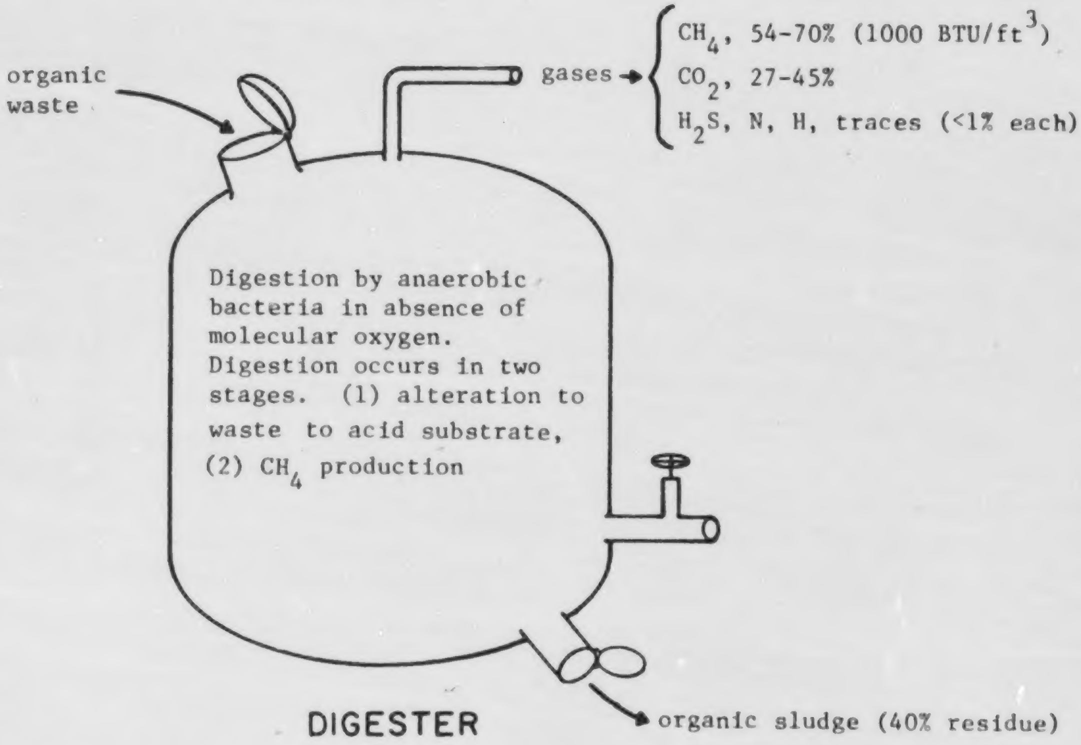
Figure 14-7


organic waste
gas; 100-400 BTU/ft^3, CO, H
Overall efficiency variable, 40 to 65%
500°-1000°C, oxygen free atmosphere
oil, 10,000 BTU/lb; (hi viscosity, corrosive)
char (may be burned to provide heat)

HEATED VESSEL, ATMOSPHERIC PRESSURE

Pyrolysis (decomposition by heat)

Figure 14-8


organic waste
gases
CH_4, 54-70% (1000 BTU/ft^3)
CO_2, 27-45%
H_2S, N, H, traces (<1% each)
Digestion by anaerobic bacteria in absence of molecular oxygen. Digestion occurs in two stages. (1) alteration to waste to acid substrate, (2) CH_4 production
DIGESTER
organic sludge (40% residue)

Bioconversion

Materials high in cellulose, and various manures, can be processed to yield oil with low enough sulphur content to be used in industrial and electric plants. Despite the excellent conversion efficiencies of hydrogenation, the heavy costs of facilities to provide high pressures and the difficulties of material injection and fuel extraction may price the process beyond broad-scale acceptance. This, more than anything else, explains why research funds are being channeled toward other waste conversion processes.

Pyrolysis, the second conversion category, is the thermal destruction of materials in an essentially oxygen-free atmosphere. The combination of high temperatures and low oxygen environment in the pyrolytic conversion vessel results in breakdown of the waste materials into three parts: (a) gases consisting primarily of methane, carbon monoxide and hydrogen; (b) an oily liquid, or tar, that is liquid at room temperatures and includes a number of organic chemicals such as methanol, and; (c) a charcoal type material which is essentially pure carbon but which includes other noncombustible materials such as rock or glass which may be introduced to the chamber.

As in hydrogenation, the pyrolytic system requires an external heat source to maintain the conversion process. Treatment of the waste gases to remove noncombustible components could allow methane and other combustibles of the pyrolytic process to serve as the primary heat source.

Since each of the three products, gas, oil and char, involve recovery at atmospheric or near atmospheric pressure, pyrolysis avoids the high pressure vessel costs associated with hydrogenation. Hence, construction and operating costs of pyrolytic converters are expected to be significantly lower. Several groups have been involved in pyrolysis research efforts; Occidental Petroleum Corp. has acquired Garrett Research and Development Co. which engineered one of the most advance systems.

In the Occidental procedure, the waste is dried and shredded, the inorganic materials are removed and the organic waste is then heated to about 500°C. in an oxygen-free atmosphere. Each ton of refuse produces almost one barrel of oil, 160 lbs. of charcoal-like material and varying amounts of low energy gas. The energy value of the oil is about 10,500 Btu per pound.

Researchers estimate that in a city of 500,000 the cost for waste disposal would be approximately $5 per ton but that materials recovery would return $6 per ton. Low Btu gas produced by pyrolysis cannot be transported great distances economically and must be used near the production site. This could prove an obstacle to the large-scale utilization of pyrolysis.

Bioconversion, or bacterial destruction of organic materials, is probably the oldest of the naturally occurring systems of degradation. Digestion of cellulose-bearing materials and other forms of organic waste has been commonplace for many years and is familiar to those who have used a septic tank as a part of the waste disposal system for home or farm.

In theory, the use of bioconversion to eliminate large quantities of waste materials appears to be a much simpler process than either hydrogenation or pyrolysis. However, organic sludge remains after digestion and, in volume, this can represent as much as 35% to 40% of the original waste introduced into the biodegradation unit.

Sludge can be dried and treated for use as organic fertilizer, but garden use would be a small outlet indeed should bioconversion become a widespread treatment method for the enormous municipal waste tonnages available in the U.S. annually. The presence of trace amounts of potentiality hazardous metals, i.e, copper, cadmium, mercury, etc., suggest the need for additional study concerning the long-term environmental effects of applying sludge to soils.

It has been suggested that the sludge be dried and used as fuel but combustion could further aggrevate the problems of atmosphere pollution. Sludge has a relatively high percentage of protein in terms of total content and could conceivably be reprocessed for use as a raw material in animal feeds.

It is conceivable that science will find ways to eliminate the undesirable characteristics of organic sludge in alternative uses and allow wider use of the significant quantities of methane produced in a biodegradation process. The methane would contain high percentages of both water vapor and carbon dioxide and would either have to be used in selected industrial processes or be treated to remove moisture and impurities, thus raising Btu levels near those of natural gas.

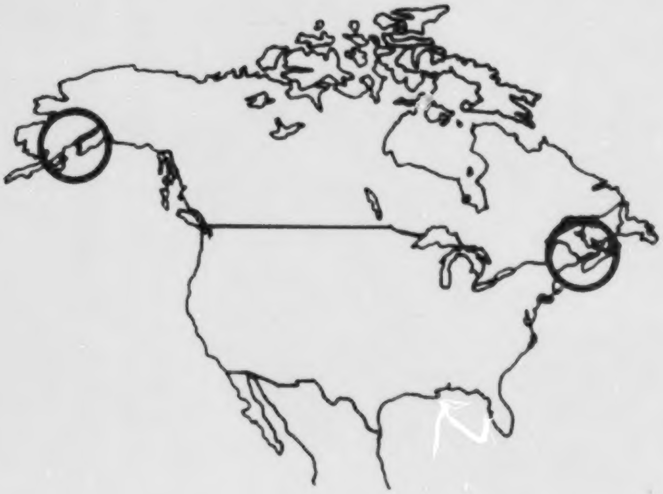
It seems logical that better methods will become available, especially if the federal government contributes more generously to the development of large-scale operational facilities capable of testing all aspects of waste collection, concentration, separation and combustion. In addition to the need for a large infusion of research dollars, the important question of the net energy yield of waste disposal methods must also be addressed.

TIDAL ENERGY

The possibility of utilizing the rhythmic tidal motions of the oceans and seas as a potential power source has attracted man's interest for centuries. Despite that long-term interest, attempts to harness the massive quantities of energy contained in the tides have achieved only limited success. While the problems serving to thwart the development of tidal-energized power generating units are numerous, five factors present challenges which will likely serve to limit the role of this intriguing energy source. The five major difficulties are:

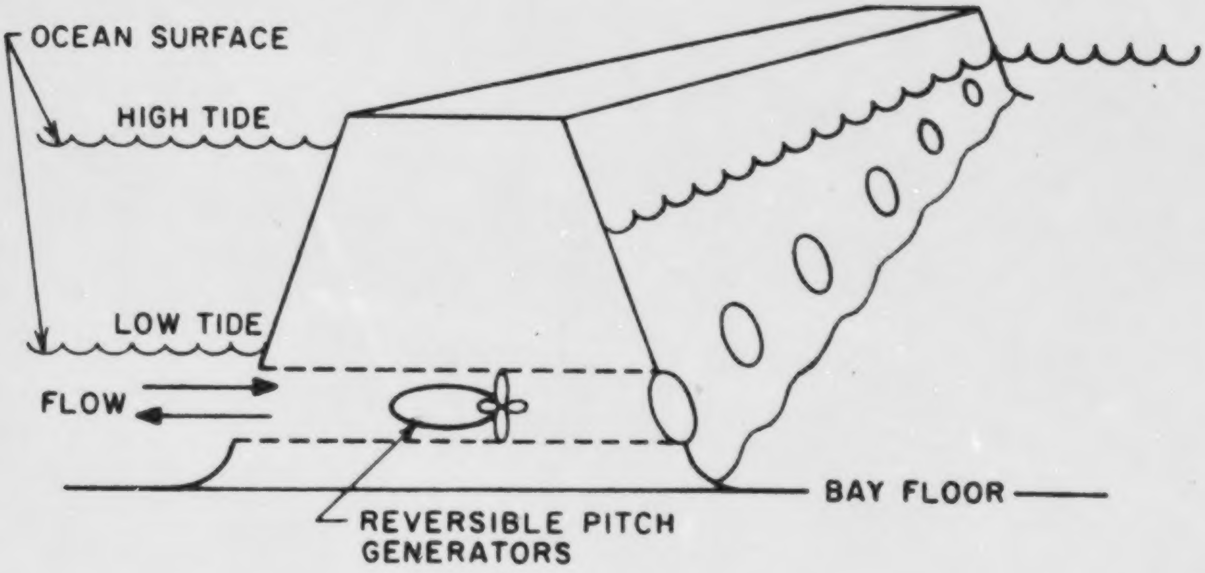
1. Tidal power plants are site specific. Generation of electrical energy in significant quantities requires the placement of barriers and/or dams containing the turbines and generators in locations which permit control of the water entering large inland bays or estuaries. (See Fig. 14-9.) Only two such locations exist on the North American continent. The best known of the two sites is Passamaquoddy Bay north of the United States-Canadian border. Passamaquoddy Bay, one component of the bay of Fundy complex, contains an area of approximately 260 square kilometers, has a mean tide of 11.4 meters and a potential generating capacity of 1,800 megawatts. Despite forty years of planning for utilization of the tidal energy existent in Passamaquoddy Bay no immediate use of the site appears likely. A second site exists on the upper, northeastern section of Cook Inlet, a short distance from Anchorage, Alaska. Both sites are identified in Fig. 14-10. The Knick Arm of Cook Inlet possess the same physical characteristics of Passamaquoddy Bay, i.e., a large bay or estuary separated from the ocean by a narrow enclosure. Knick Arm displays a mean tide of 7.7 meters and an estimated electrical generation capacity of 9,500 megawatts. Calculations concerning the power produced by a conventional hydroelectric unit employ the equation $P = (W/T) \cdot H$ where W/T is the rate of water flow, and H the height of fall. In estimating the potential of a tidal system the equation must be divided by two to reflect the average of the high and low tide levels. Problems designed to demonstrate the differences in the energy yields obtained from a given volume of water can be developed for local sites such as San Francisco and Humboldt Bays in California and compared with sites such as Knick Arm or Passamaquoddy Bay.

Figure 14-10



Tidal power unit sites

Figure 14-9

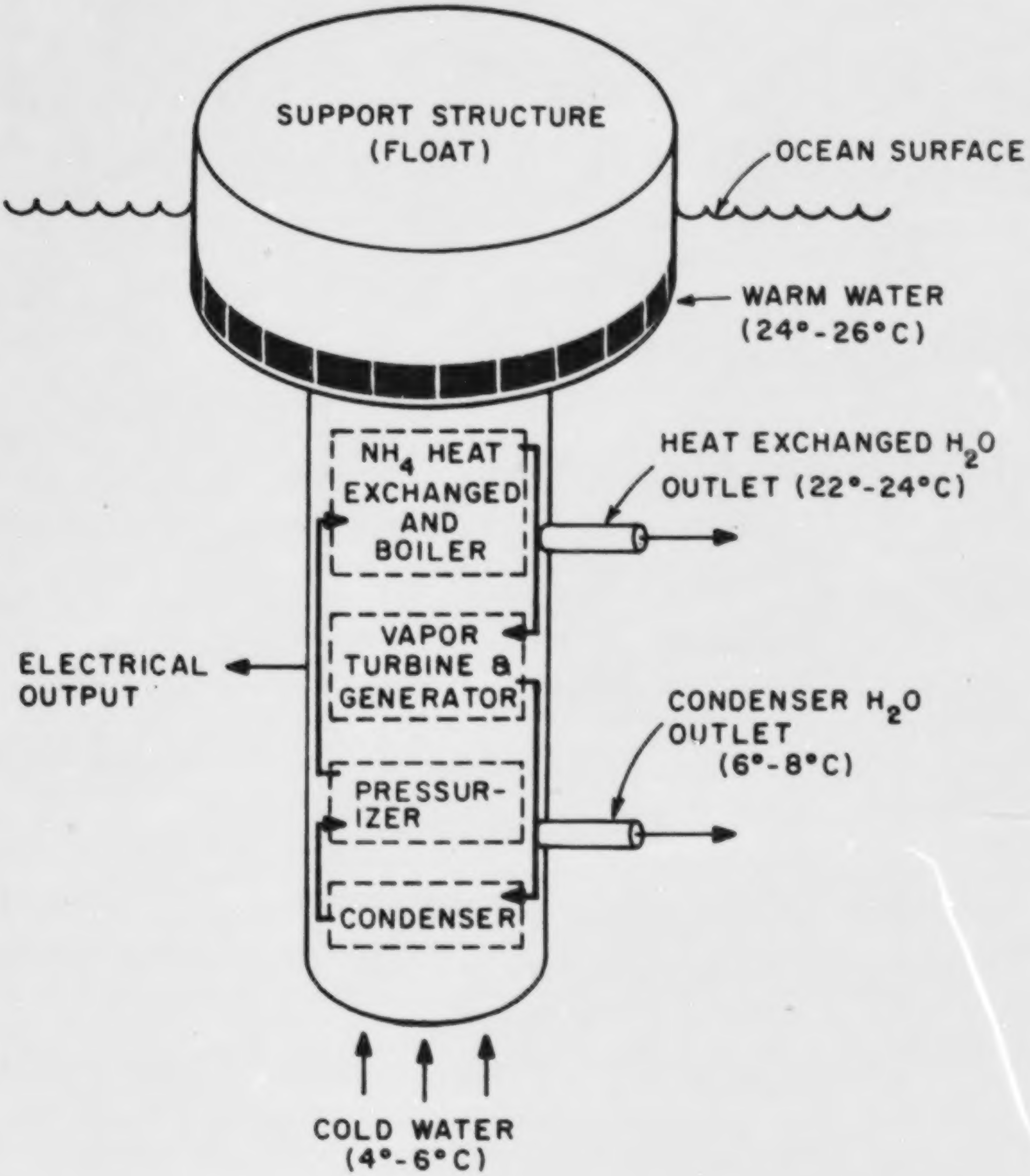

OCEAN SURFACE
HIGH TIDE
LOW TIDE
FLOW
BAY FLOOR
REVERSIBLE PITCH GENERATORS

Tidal power unit schematic

2. The remote locations of the better sites relative to energy consumption centers. Of the two sites noted, Passamaquoddy Bay is reasonably close to industrial and urban load centers. The upper Cook Inlet site is, except for the Anchorage area, so distant from other areas of significant energy consumption that the economic feasibility of the project due to energy losses through transmission and storm damage to transition apparatus becomes uncertain.
3. Because the arrival of each high tide occurs 25 minutes later than the previous high tide a problem of "phasing" the periods of generation to the periods of energy needs arises. With energy demand related in large part to the industrial-urban activities conducted during daylight periods, it becomes apparent that if tidal power is to function as one component of an integrated energy system some sort of energy storage system is needed. Although energy cannot be stored as electricity (except in capacitors), energy "retiming" systems, such as may be achieved through the use of pumped storage of water or compressed air, offers a feasible solution. Pumped water storage is used extensively in the United States and offers a ready, although site-specific alternative. Storing energy as compressed air in underground taverns is a relatively recent development and utilizes excavations in solid rock or solid domes. The conversion of the energy stored as compressed air into electricity is a simple, relatively inexpensive procedure. Gas turbines, of the type utilized for meeting the "peaking" demands of public utilities, separated from the compressor section of the units, are employed to energize the generators tied into the electrical grid. The result is an instantly responsive, efficient, energy storage system!

4. Inordinately large capital investment costs/KW. Analysis of the total probable cost associated with development of tidal power units suggests that even if the feasibility of such units were demonstrated the costs/benefits ratio would preclude their use. The construction of the dams and water control structures in environments which may prove to be unusually demanding, the use of metals and materials resistant to the ravages of corrosion and electrolysis and the development of efficient, low maintenance, reversible flow turbine-generators combine to create monumental technological-operational challenges.
5. Possible adverse environmental effects. Tidal-energized power generating units are cited by some proponents as one example of an environmentally acceptable energy conversion procedure. If the comparison involves a typical thermal generating unit it certainly is true that the environmental problems associated with thermal releases from cooling water and alteration of the atmosphere via the introduction of the products of combustion do not exist. But other disturbances will likely result! A study of the sites identified as appropriate for tidal power units demonstrates that each is located at the entrance of the bay or large estuary. In both Cook Inlet and the Bay of Fundy, shipping, fishing and the numerous activities associated with those major industries rely to a very great extent upon open, uncluttered passageways between the upper areas of the bay and the ocean. While the problems of water-borne commerce can be solved through the use of locks or delays in vessel

Figure 14 11


SUPPORT STRUCTURE
(FLOAT)
OCEAN SURFACE
WARM WATER
(24°-26°C)
NH_4 HEAT
EXCHANGED
AND
BOILER
HEAT EXCHANGED H_2O
OUTLET (22°-24°C)
VAPOR
TURBINE &
GENERATOR
ELECTRICAL
OUTPUT
CONDENSER H_2O
OUTLET
(6°-8°C)
PRESSUR-
IZER
CONDENSER
COLD WATER
(4°-6°C)

Ocean thermal gradient generating unit schematic movements, solutions directed to correcting the consequences of impeded movements of important marine species are less easily discerned. Estuaries provide an inordinate proportion of the small marine organisms which serve as the first stage in a long chain of events leading to the availability of commercially important food species. The development of tidal units possessing potential for gross alterations of fragile marine ecosystems mandates the need for thorough and dispassionate study.

Given the conditions noted, questions arise as to the future of tidal power units. Energy-wise, the future is uncertain. And the longer the period of projection the greater the probability of significant error. Projections based upon current (1977) energy cost would suggest that near-term development of tidal power units is unlikely. Recent and continuing massive escalations in the cost of petroleum indicate that energy systems unattractive today may prove valid a decade or two hence. As has been demonstrated in the discussions concerning other energy systems, no "perfect" system exists. As energy costs increase and the availability of energy released through finite fuels diminishes, man may be forced to develop some of the less easily exploited energy sources such as tidal units.

OCEAN THERMAL GRADIENTS

Visualize the oceans, which cover 72% of the globe, as an immense solar energy collector and storage unit. If one does so, it is likely that questions will arise concerning the possible use of that energy for the generation of electricity and/or secondary fuels such as hydrogen. Fortuitously, for bath swimmers and those interested in power generation, significant and essentially constant differences in the thermal characteristics of the upper ocean surfaces and ocean depths exist over much of the globe. The maximum differential exists in the equatorial regions where ocean surface temperatures of 80°F can be contrasted to 40°F temperatures at depths two to three thousand feet below the surface. Although the $T_1 - T_2$ differences noted for the ocean thermoclines offer minor values in comparison to the temperature differences achieved in modern thermal-generating units, low temperature "heat engines" may prove to offer a feasible procedure for converting a part of the oceans' thermal load into energy forms beneficial to man. The technical aspects of exploiting the thermal energy stored in the surface of the oceans are not complex and can be compared to the operating principles of a household refrigerator or air conditioner unit. Domestic refrigerators and air conditioners use a fluid such as Freon to absorb heat energy from inside a refrigerator, freezer or interior of a home. Internal heat absorption is achieved through the conversion of pressurized liquid Freon to a pressurized gas. The warmed gas is then circulated to an external condensing unit where the thermal load is dissipated to the atmosphere. The gas, cooled and pressurized, returns to liquid form and the cycle is repeated. Exactly the same principles apply to the units proposed for extracting thermal energy from the oceans. In ocean thermal units, solar heat energy, stored in the surface water, would be utilized to vaporize (boil) a working fluid such as propane. The vaporized fluid would pass through a turbine-generating unit, be condensed in a cooling coil exposed to low temperature ocean water and recycled. Study of the ocean thermal gradient schematic provided in Fig. 14-11 permits analysis of the complete vaporization-power generation-condensing process.

Achievement of the maximum temperature differentials required for successful operation of OTG units mandates the siting and physical requirements of such devices. Since the maximum ocean surface temperatures occur closest to the equator it is apparent that equatorial locations offer the greatest warm water potential. Need for the coldest water readily available dictates the use of an extended intake structure, possibly two to three thousand feet in length, to cool the condensers. Required then, is a floating device which can be anchored offshore in an area where both needs can be met. Many researchers believe that the difficulties relating to the design of units capable of withstanding tropical storms, transmission of the energy developed to consumption areas, etc., can be resolved without undue difficulty.

Estimates concerning both capital costs and the probable cost of the energy produced vary widely. Advocates emphasize the fact that ocean thermal gradient units would not require costly "fuels," that they would be completely independent of external fuel sources, and that the environmental degradation potential appears to be minimal. Analysis of the arguments presented in support of OTG power generating units suggest that while such devices may not appear especially promising in the 1970's, by the year 2000 OTG units could prove to be one of the better energy conversion procedures available.

CHAPTER 15

HYDROGEN AND FUEL CELLS

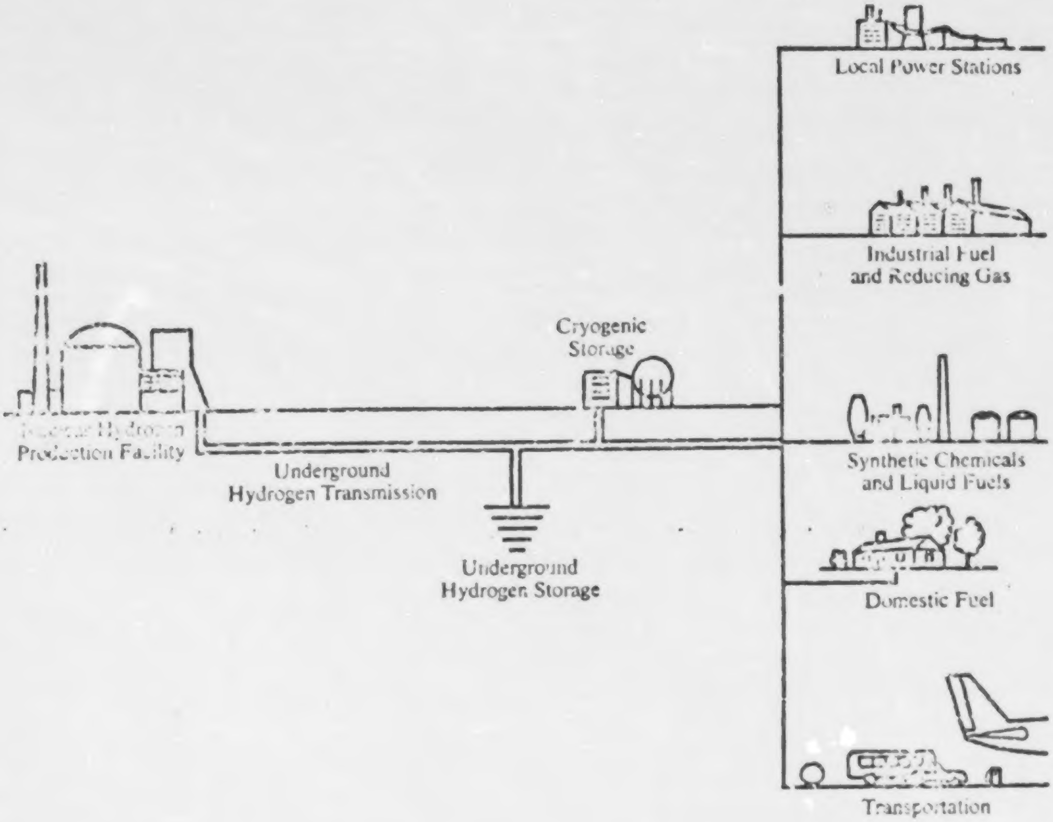
Secondary Chemical Fuels

Although much of our energy related research today concentrates on the production and utilization of electricity, it is imperative that other secondary energy forms also be considered. For example, approximately 50% of the costs involved in using electricity is attributable to transmission and distribution. Additionally, electricity does not lend itself well to a number of applications.

Pipelines are another way to transport energy; we now use an extensive pipeline system to transfer natural gas from one point to another. It is entirely possible that through the conversion of thermal and/or electrical energy into a secondary energy form, such as hydrogen, the hydrogen could be transported from areas of production to areas of consumption without many of the aesthetic and economic drawbacks of high-voltage transmission lines. The possible use of hydrogen as a universal, ecologically acceptable fuel provides the foundation for a concept often termed, "the hydrogen economy." (See Figure 15-1)

Despite the fact that the utility members of the gas industry are taking a number of significant steps to supplement the nation's declining supply of natural gas, it is obvious that on a long-term basis, natural gas cannot continue to provide the basic energy requirements needed for a large part of this country's economy. Importation of natural gas in its liquefied form and the development of synthetic natural gas from coal and other feedstocks will certainly serve to extend natural gas availability (which met about 40% of the total U.S. energy needs in 1975). However, costs will increase markedly.

Figure 15-1


Local Power Stations
Industrial Fuel and Reducing Gas
Cryogenic Storage
Nuclear Hydrogen Production Facility
Synthetic Chemicals and Liquid Fuels
Underground Hydrogen Transmission
Underground Hydrogen Storage
Domestic Fuel
Transportation

A major portion of the natural gas used in the U.S. is either for space heating and hot water heating in commercial and residential units or for the production of process heat used in industry and manufacturing.

Encouraging, study suggests that hydrogen may be used in place of natural gas, even to the point of using existing storage and natural gas transmission systems. There are at least three significant reasons why hydrogen merits serious consideration:

1. Hydrogen is essentially nonpolluting; no carbon monoxide, sulphur dioxide, hydrocarbons or particulates are produced in the combustion process. The small amounts of NO_x which are procured can be reduced through controlled combustion, and NO_x from hydrogen occurs in far less volume than from combustion of fuels.
2. Hydrogen supplies are virtually unlimited. The raw materials required for hydrogen production are water and large quantities of energy. Unfortunately, the energy requirements for large-scale hydrolysis of water pose the major technical and economical barrier to the possible widespread substitution of hydrogen for natural gas.
3. Hydrogen possesses an advantage not present in today's electrical energy systems, that of storage. Hydrogen can be stored either as a gas or liquid, and in either form it is transportable over long distances at costs substantially less than those of transmitting electrical energy.

One disadvantage of hydrogen is its low Btu content, 325 Btu/ft.^{3} (1,050 Btu/ft.^{3} for natural gas). However, hydrogen can be used directly in modified commercial and domestic heating appliances and internal combustion engines. The requirements for adapting existing units to hydrogen are inexpensive and easily achieved.

Hydrogen Production Techniques

Production of hydrogen through electrolysis is widespread and has been commonplace for many years in areas where electrical energy is relatively cheap. Canada, India and Norway are a few of the countries where electrolytic decomposition of water to produce hydrogen and oxygen constitutes a major production technique. The efficiency of existing electrolytic processes is relatively low, between 50% and 60%. Many believe that with additional research and development, this efficiency can be improved.

Another process for obtaining hydrogen involves the disassociation of water into hydrogen and oxygen under extremely high temperatures, (>2,500°C). Development of the temperatures required represents a technological challenge of considerable magnitude as do the problems associated with separation and purification of the hydrogen and oxygen thus produced.

Another procedure, called thermo-chemical splitting, relies upon a series of chemical reactions in which the intermediate chemicals are recycled. The overall reaction produces hydrogen and oxygen in two separate steps. Evidence to date suggests that such processes are feasible but that additional research will be required to develop the temperatures and facilities required for economic production of hydrogen in large quantities.

Utilization

Hydrogen consumption in the U.S. amounts to more than 2.3 trillion cubic feet per year, with the majority of that directed to two specific applications -- ammonia production, 42%, and petroleum refining, 38%. If hydrogen could have replaced natural gas as a primary energy source in 1975, approximately 60 trillion cubic feet would have been required to satisfy U.S. demand.

In addition to direct use as a possible replacement for natural gas, hydrogen could play an additional role in the production of synthetic gas and oil. For example, in producing synthetic crude from coal, around 6,500 cubic feet of hydrogen is required for every barrel of petroleum manufactured. Coal gasification for SNG would consume some 1.5 cubic feet of hydrogen for each cubic foot of SNG produced.

As we pointed out, one of the most significant energy differences between natural gas and hydrogen is the smaller Btu content per cubic foot of hydrogen. In a practical sense, this means that it takes three times as much hydrogen to produce the results obtained from a given volume of natural gas. However, since the density of hydrogen is about 1/3 that of natural gas, roughly the same number of Btu's can be pumped through a pipeline or distribution facilities at equivalent pressures.

A second important difference between natural gas and hydrogen is the considerable differences in the velocity of flame, or combustion speed, of hydrogen over natural gas. Because hydrogen possesses a much higher flame velocity than natural gas, boilers or heating units designed to operate on natural gas must be modified before hydrogen can be used as a replacement fuel. Use of hydrogen requires an additional caution in that hydrogen-air mixtures are combustible (explosive) over a much wider range than natural gas -air combustion. While natural gas and air mixtures are combustible within a narrow range (5-15%), hydrogen-air mixtures are reactive over a much wider range, i.e, 4 to 75%.

Despite the possible danger noted, hydrogen represents a very large environmental plus over the use of fossil fuels, because the combustion process yields only water vapor and minor amounts of oxides of nitrogen as by-products. There is no concern over controlling the CO and CO_2 produced in traditional combustion units or internal combustion engines.

Transportation is an area of extensive potential for hydrogen. One of the major impediments to the use of hydrogen is the fact that gaseous hydrogen is bulky and requires the use of heavy and expensive containers. It is entirely possible to use liquid hydrogen, but the state-of-the-art in cryogenic containment and transport must advance dramatically for such liquid hydrogen use to become a reality.

The possibility of using wind turbine units to electrolyze water and produce hydrogen for domestic space and water heating represents yet another possibility for hydrogen. Or it may be that a major hydrogen market will arrive with the development of domestic units which can produce both electrical energy and direct heat from environmentally "clean" hydrogen.

A deterrent to the wider use of hydrogen is the high cost of the facilities required for large-scale hydrogen production. If it were necessary to acquire the same amount of energy from hydrogen as is contained in 21 trillion cubic feet of natural gas, electric generating capacity of more than 1 million megawatts would be required. With total U.S. generating capacity at about 350,000 megawatts, it is apparent that an increase of three- to four-fold would be required for the specific purpose of hydrogen production. If one assumes that the 350,000 mw U.S. capacity is used at an on-stream factor of 50% or less, the use of electrolysis during "off-peak" electric demand could be a possible method of producing H_2 with existing units at much more attractive cost.

Storage and Transmission

Let's examine next the comparative cost of transmitting natural gas, electricity and hydrogen. The installation costs of underground electric transmission facilities are much higher than those for gas pipelines. It is also apparent that overhead AC transmission facilities are far less expensive than underground lines. The price tag of natural gas lines of similar rated capacity is relatively inexpensive.

Hydrogen storage can be achieved in large tanks similar to those used for natural gas storage or underground in depleted gas fields. (Natural gas is stored today in many depleted California fields.) The fact that hydrogen is of less density than natural gas suggests that leakage may be somewhat more prevalent although still negligible. A second technique for storing hydrogen is through liquefaction. Reduction of gaseous hydrogen to liquid reduces the volume at a ratio of 600 to 1.

Safety

Discussions of hydrogen seem inevitably to get around to the "Hindenburg Syndrome," a term recalling the accidental ignition of hydrogen used to fuel the dirigible, Hindenberg, at Lakehurst, New Jersey, in 1936. That disaster has ever since conditioned many to fear the use of hydrogen as a fuel.

Without question, the safe management and handling of fuels, including hydrogen, must be a major consideration.

It is probably fair to state that under today's regulations concerning fuel storage, transfer, and utilization, hydrogen probably represents no greater hazard than other gaseous fuels. The flammability range of hydrogen and its mixtures is the widest of any gaseous fuel, varying from 4% to 75% hydrogen by volume.

Natural gas-to-air mixtures demonstrate a much smaller flammability range, in the order of 5% to 15%. The lower limits are essentially the same for the two fuels; however, the higher diffusion rate of hydrogen, owing to its low density, tends to make it safer than natural gas under the same conditions.

Probably the most significant characteristic of hydrogen-air mixtures is low ignition temperatures, about one-tenth the heat which will ignite gasoline or natural gas mixtures. Clearly, hydrogen has both advantages and disadvantages. As with any other fuel, safe use requires operating procedures which preclude both accidental ignitions and unscheduled releases.

Perhaps its most serious safety hazard is hydrogen embrittlement of steel at high pressure which could cause failure of existing natural gas pipelines if used to transport hydrogen. H_z also burns with a clear flame; since leaks will "auto ignite," and can't be detected visually, this can lead to safety problems of different magnitudes than those common to natural gas.

Economics

Economics indicate very clearly that hydrogen manufacture requiring high energy inputs will not be less expensive than natural gas and other naturally occurring fuels. Using today's electricity costs and U.S. ERDA estimates for large-scale hydrogen electrolysis plants, however, hydrogen energy could be sold more cheaply than electrical energy. There will not likely be a major market for hydrogen at such prices, though, as long as natural gas remains relatively inexpensive.

As the price of both natural gas and electricity increase, hydrogen could become more commercially feasible. With the economics of hydrogen closely linked to the cost of electricity, one can speculate that electrical or thermal energy from breeder and/or fusion reactors will accelerate the advent of the hydrogen economy.

FUEL CELLS

Fuel cells are electrochemical devices capable of converting chemical energy into DC electricity. Fuel cells offer significant promise of contributing in different ways to the energy needs of the future. They are not unlike wet-cell batteries in that both contain anode, electrode and electrolyte. However, there the similarity ends, for fuel cells rely on a continuous supply of reactant materials, most commonly hydrogen and oxygen, to generate low-voltage DC current.

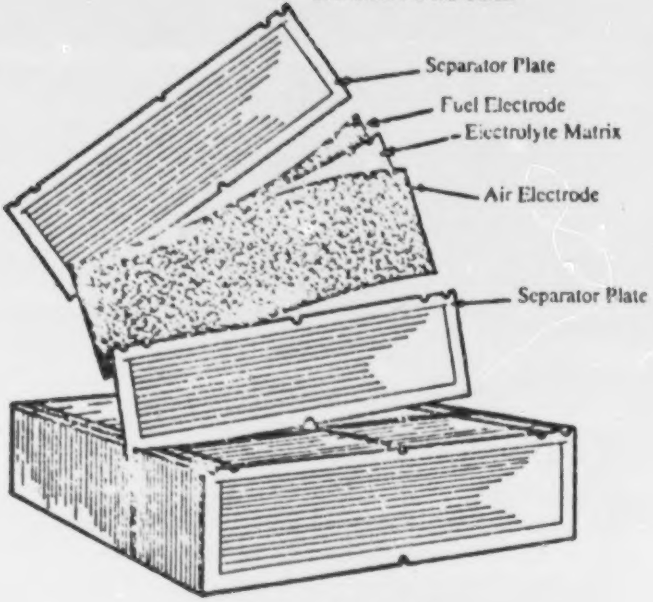
Fuel cells are not new, having been discovered by the Englishman, Sir William Grove, in 1839. Fuel cells, like solar cells, can be joined in parallel and series combinations to produce the power required for specific tasks. Figure 15-2, showing a schematic of typical hydrogen-oxygen fuel cell, depicts the reactions through which a fuel cell converts chemical energy to electrical energy.

In a simple hydrogen-oxygen fuel cell, hydrogen is fed to the anode (-) where the hydrogen gas forms hydrogen ions (H+) and gives up electrons in the process. The electrons travel along the external circuit to the cathode. The energy produced by the fuel cell is tapped by placing an electrical "load"

Figure 15-2

FUEL CELLS

SINGLE FUEL CELL


Separator Plate
Fuel Electrode
Electrolyte Matrix
Air Electrode
Separator Plate

A typical fuel cell assembly for a prototype commercial fuel cell. [*Source: Pratt & Whitney Aircraft.*]

between the cathode and the anode. The reactions taking place within the hydrogen-oxygen fuel cell are as follows:

At the anode: $H_2 \rightarrow 2H^+ + 2\ e^-$

At the cathode: $O_2 + 4H + 4\epsilon^- \rightarrow 2H_2O$

Overall: $2H_2 + O_2 \rightarrow 2H_2O$

At the anode, the pure hydrogen gas diffuses through a porous material and reacts with hydroxide ions within the electrolyte to produce water and liberate electrons. The formula is as follows:

$$2\ H_2 + 4OH \rightarrow 4\ H_2O + 4_e^-$$

A catalyst implanted in the porous electrode, most commonly of platinum, causes the reaction to occur at moderate temperatures. Electrons flow through the external circuit to the cathode where oxygen and gas diffuse through the catalyst-containing electrode to produce this reaction:

$$O_2 + 2H_2O + 4_e^- \rightarrow 4OH$$

The hydroxide ion generated completes the electrical circuit by migrating through the electrolyte to the anode. Although the fuel cell described utilized bydrogen and oxygen, air may be substituted for oxygen with a slight alteration in efficiency. Platinum is the most effective catalyst but the quantities of this metal are insufficient to support a large fuel cell industry. Palladium is also a good catalyst. Quite possibly, continued research will demonstrate the feasibility of using other, less expensive metals.

Fuel cells using other types of fuels exist. Some combinations that have been tried experimentally are hydrogen-air, carbon monoxide-air, natural gas-air, ammonia-air, zinc-oxygen and aluminum-oxygen. All show promise but involve either lower efficiencies or greater technological requirements than H-O fuels.

Fuel cells have received considerable attention because of a number of advantages over other energy systems.

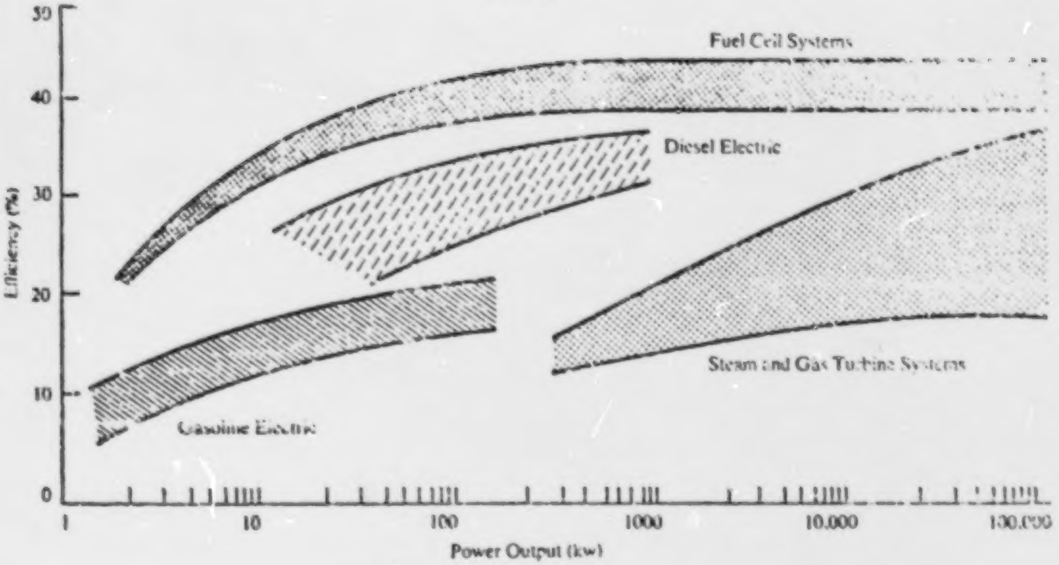
1. Fuel cells emit few pollutants.
2. Operation is quiet, and the cells operate at low levels of heat loss. Almost all inefficiency shows up as heat. Cells must be cooled. Temperature control is very critical. Heat is recooled by air cooling and could be used for space heating.
3. Conversion efficiencies are high over a wide range of power output levels, especially at part load. For example, the efficiencies of the most modern fossil-fueled thermal units are slightly more than 40% when operated at peak output levels. Fuel cells may be operated over a broad range of output requirements with relatively high overall efficiencies (50-60%). (See Figure 15-3)

Although the major application of fuel cells to date has been in meeting energy requirements for space vehicles, it's entirely possible that technical advances will produce small-scale fuel cells for use in homes and small businesses.

Applications - Existing and Potential

Electric utilities are funding the development of the FCG-1 utility fuel cell with United Technology. The Electric Power Research Institute is spending millions of dollar each year on pure and applied fuel cell research. Because of high operating efficiencies and the nonpolluting nature of fuel cells, such units conceivably could be used as peaking facilities in major urban areas. They are also attractive for base loading when coupled with a coal gasifier.

Figure 15-3



Thermal efficiency of electrical production of fuel cells and other types of generators as a function of output.
[*Source: Pratt & Whitney Aircraft.*]

The environmental advantages of fuel cells suggest a potential for use in critical air basin areas such as Los Angeles. Such use could be in electric power plants or even in motor vehicles which are the primary source of atmospheric pollutants. The latter constitutes an admittedly difficult application, because mobile fuel cell units are expensive and have lower power output and fuel limitations.

At least two major projects to test the feasibility of the fuel cell for large-scale electric generation are underway. The first project, sponsored by the Office of Coal Research, U.S. Department of the Interior, is to develop a fuel cell that operates on coal.

The coal reacting power plant is actually an indirect fuel cell in that the coal is gasified, and the hydrogen produced through that process is thus utilized in the generating unit. OCR estimates that because of an anticipated 60% efficiency of the proposed unit, an additional 50% in electrical energy can be obtained from each ton of coal over what might be achieved in a conventional thermal plant.

A second major effort toward utilization of fuel cells is being pursued by the Team to Advance Research for Gas Energy Transformation -- TARGET, for short. TARGET is really 32 gas utility companies which, together with the United Technologies Corp. are funding research on a small off-site fuel cell unit which could power homes, apartments, stores, restaurants, offices and small industrial complexes.

The TARGET fuel cell system is designed to run on natural gas and to be located within or right beside the energy consuming area. Losses generally associated with transmission of electricity will thus be avoided. TARGET's system, like OCR's coal-fueled system, is an indirect fuel cell where steam is used to decompose the natural gas to hydrogen and carbon dioxide.

One discouraging element in fuel cell research is the declining federal support provided for fuel cell activity. For example, federally funded research in 1963 came to nearly $16 million. By 1970, fuel cell funding had declined to slightly under $3 million. However, recent allocations by ERDA for research in fuel-cells have increased over previous years.

It is believed that with existing technology, and on a large-scale production basis, fuel cell energy conversion systems could be constructed for $350 to $450 per kilowatt. The life goal is 40,000 hours or about 5 years. For peaking service this is equivalent to operating 20 years or more. The operating cost of fuel cells include cell replacement costs which can extend fuel cell life to any desired period, if economics allow.

Economics

Projecting the future of fuel cells is difficult. However, there is wide belief that fuel cells may well provide a not-too-distant substitute for some conventional fossil-fuel consuming thermal plants. Higher initial costs of fuel cell power plants may be offset by increased efficiency (i.e., decreased fuel consumption) and the inherently superior environmental qualities of fuel cells.

MAGNETOHYDRODYNAMICS (MHD)

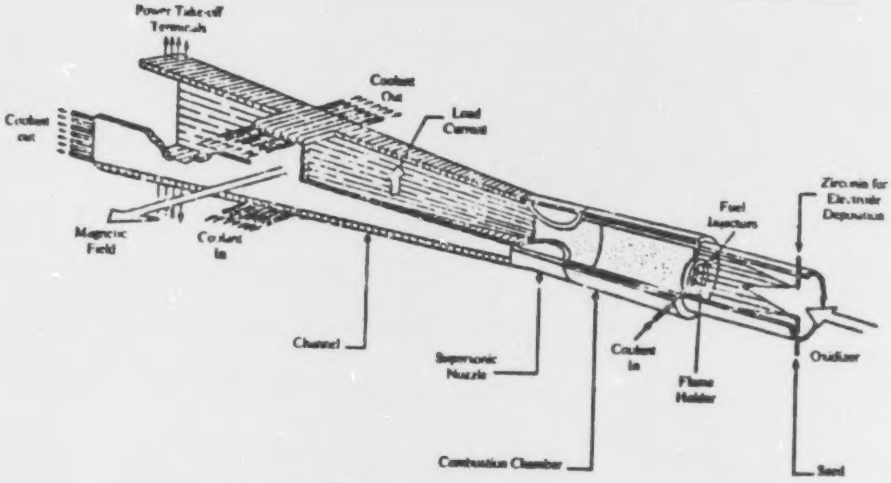
Magnetohydrodynamics (MHD), is an impressive term for a process which really represents an energy conversion system whose principles have been known for more than 100 years. MHD power generation is achieved when an easily ionized metal such as potassium is injected into a high-temperature combustion gas, expanded to high velocity through a nozzle and then directed into or through a magnetic field such as is found in a DC generator.

The magnetic field has north and south poles, and as the ionized gas passes between the magnetic poles, it induces a flow of electrical current which can be picked up by electrodes adjacent to the poles. The basic difference, then, between an MHD and a turbine-driven generator is the substitution of ionized gas for a rotating conductor. Although simple in concept, MHD development has been delayed by materials problems caused by temperatures required for ionization of the gases, by the distribution of seed materials within the gas or plasma, and by the collection and recycling of the seed materials.

Within the past few years, the technology has matured to the point that MHD now represents an energy conversion system of considerable promise. A significant portion of the impetus for the development of MHD conversion units traces to their high thermal efficiencies, 50% to 60%, compared to the 30% to 40% for conventional fossil units.

Figure 15-4 shows the movement of the ionized plasma stream between the north and south magnetic poles with the deflection of the positive and negative particles to the cathode and anode. A MHD generator includes a combustion chamber, a nozzle or channel to direct the flow of gases, powerful magnets, and electrodes to collect the electric current.

Figure 15-4


Power Take-off Terminals
Coolant Out
Load Current
Coolant out
Magnetic Field
Coolant In
Channel
Supersonic Nozzle
Combustion Chamber
Coolant In
Flame Holder
Fuel Injectors
Zirconia for Electrode Deposition
Oxidizer
Seed

. One possible configuration for an MHD generator.

A power plant using an MHD generator would also require a heat exchanger to preheat the air fed into the combustion chamber and stack gas cleaning equipment to remove particulates from the exhaust gases.

Although MHD generators operate at temperatures above 2,000°C., those temperatures are not high enough to ionize the combustion gases completely or to make them electrically conductive. The low conductivity rate is overcome by injecting small quantities of seed metals, usually salts of potassium. The potassium compounds are recovered from exhaust gases and recycled for both environmental and economic reasons.

One proposal for minimizing the thermal losses associated with MHD generators is to develop what are termed "combined" MHD-steam-turbine electric plants. In the combined units, the hot exhaust from the MHD unit would provide both heated air for the MHD combustion chamber and steam for a turbine generator cycle. The overall efficiency of a combined unit would be greater than that achieved either by MHD or traditional turbine units individually.

In addition to the open-cycle MHD system discussed above, two other MHD systems are under intensive study. The closed-cycle MHD system utilizes a gas such as helium which is continuously circulated through a closed loop. One of the advantages of the closed-cycle system is the utilization of lower temperatures, 1700° to 1900°C., which may increase the opportunity to use the closed-cycle procedure in some of the more traditional steam-turbine type applications. A disadvantage is that efficiency tends to decline with the temperature reductions.

The third MHD system uses liquid metals in a cycle similar to that employed for the closed-cycle system. The advantages of using metal as a working fluid include higher electrical conductivity, improved thermal characteristics and the utilization of lower power magnets. The disadvantages arise from the difficulties associated with accelerating a heavy mass to velocities required for efficient power generation.

The many apparent advantages of MHD units (i.e., high efficiencies of operation, reduced thermal pollution, extension of domestic fuel supplies) are off-set in part by some of the continuing difficulties associated with the developing MHD units.

Natural gas and petroleum, the fuels most readily utilized in MHD units, are finite. It is natural, then, to direct MHD research toward utilization of coal, our most abundant fossil fuel. Research efforts are encountering difficulties with ash and mineral residues in coal which tend to "short circuit" the ionization process required for the generation of electricity. An additional drawback of the ash, minerals and particulate matter is their tendency to short the collecting plates and reduce the effectiveness of the magnets.

In time these deficiencies will no doubt be overcome. On the basis of the evidence presented to date, MHD appears to present considerable promise as a means of extending domestic supplies of fossil fuels while permitting an extension of non-nuclear fuel power generation facilities.

Despite the breakthroughs noted, MHD is in a very primitive state of development when compared to fuel cells. Unless extra ordinary advances occur, it does not seem at all likely that MHD will be a significant factor in power generation until well after the year 2000.

CHAPTER 16

BREEDER REACTORS

A major disadvantage of the "burner" nuclear reactors now used for power generation in the U.S. is their consumption of the limited supply of U235 available within the continental U.S. U235, the sole naturally occurring fissionable radioisotope, comprises only 0.7% of natural uranium. Although estimates of the supply of U235 vary and are cost-related, there is general agreement that the 235 isotope exists in relatively small quantities.

The four isotopes available in quantities sufficient to sustain a fission process, are U233, U235, Pu 239 and Pu 241. All but U235 must be produced artificially. Production of a fissionable material involves the use of a "fertile" material such as U238 or Th 232 which, when exposed to high levels of neutron flux, produces fissionable materials which can be used as fuels in nuclear reactors.

The absorption of a neutron by Th 232 or U238 does not result directly in new fissionable materials but first produces unstable, intermediate products. As indicated in the equations, the intermediate products quickly decay to produce the fissionable material desired.

(a) $(232_{Th})+_{n}^{*} \rightarrow (233_{Th})\ \frac{\text{rapid}}{\text{decay}}\ (233_{Pa})\ \frac{\text{rapid}}{\text{decay}}\ (233_{U})\ \frac{\text{slow}}{\text{decay}}$

(b) $(238_{U})+n \rightarrow (239_{U})\ \frac{\text{rapid}}{\text{decay}}\ (239_{Np})\ \frac{\text{rapid}}{\text{decay}}\ (239_{Pu})\ \frac{\text{slow}}{\text{decay}}$

(c) $(240_{Pu})+n \rightarrow (241_{Pu})\ \frac{\text{slow}}{\text{decay}}$

---

*The letter n represents a neutron. The decay of intermediate products results in each case above in the emission of a beta particle. A rapid decay means that the process will be essentially complete in seconds, hours or months, while a slow decay requires hundreds to hundreds of thousands of years.

As the equations show, ^{232}Th is converted to thorium-233, which decays to protactinium-233, which then decays to the desired fissionable material, ^{233}U. When ^{239}Pu is formed from ^{238}U, the intermediate products are uranium-239 and neptunium-239. Plutonium-241 is formed directly from ^{240}Pu.

The "breeder" reactor obtains its name from the fact that it can produce more nuclear fuel than it consumes. Breeder reactors start with a load of fissionable fuel, i.e., U235, which contains in addition to the U235, large quantities of either U238, Pu 239 or Th 232.

The conversion of U238 into Pu239 is not restricted to breeder reactors. The present generation of "light water" reactors converts U238 into Pu239 at a ratio of about .55 grams of Pu239 produced for each gram of U238 consumed.

It must be emphasized that breeder reactors do not produce new fissionable fuels "for nothing" in a sort of perpetual motion process. The conversion process occurs only under a set of very specific and rigidly controlled conditions that to date have presented a substantial challenge to researchers. Conversion is not an immediate process. Calculations suggest that production of a given quantity of fuel equivalent to that contained in the original fuel load will require 10 to 20 years. Breeder reactors are in many respects similar to the existing generation of light water reactors. Let's look into these similarities as well as some important differences.

Similarities and Differences between Burner and Breeder Reactors

Of the existing generation of nuclear reactors used to produce electricity, high temperature gas cooled reactors (HTGCR) come closer to being true "breeders" than any of the other types. HTGCR's produce almost as much fuel as is consumed. The fuel of a typical HTGCR is a mixture of highly enriched uranium and thorium compounds. The U235 is required to initiate the fission reaction, and some of the neutrons released react with Th232 to produce U233.

Similarities between breeders and conventional reactors are numerous. Both require containment vessels and use neutron absorbing materials as a major part of their control mechanism. The cores of each contain concentrated quantities of both fissionable and fertile fuels. Both rely on neutrons as trigger "mechanisms" for initiating the fission reaction, both use coolants, and both utilize safety devices with redundant "backups" systems to insure safe operation.

Though markedly similar in general appearance, important differences do exist. The breeder reactor, which capitalizes on fast neutrons for the breeding process, eliminates the need for a moderating fluid or material. Coolants in breeder reactors serve as coolants only.

In contrast to the use of neutron absorbing materials in LWR's as a means of capturing the excess neutrons, breeders use excess neutrons productively by absorbing them into fertile material. However, due to the reduced number of delayed neutrons and the more highly concentrated form of the fuel, breeders require a much higher degree of precision in their control processes. And, finally, because of the greater neutron economy achieved from a compact core and reduced loss of neutrons from parasitic absorbtion, breeder reactors are able to use 50% to 70% of the fuel that is contained within the fuel rods (versus an average of 2% for LWR's). Nuclear Regulatory Commission (NRC) experts suggest that this greater fuel efficiency can reduce uranium needs by more than 1 million tons over the next 50 years, an important, if realizable, objective.

The Breeding Process

When a neutron strikes the nucleus of an atom, a series of evants is set in motion. The number of neutrons released per fission varies but averages about 2.47 in thermal reactors. Since only one neutron is needed to perpetuate the fission chain reaction, the excess neutrons can, in the case of breeder reactors, be used to produce fissionable materials.

But the process is not all that simple, for other fates can await the neutrons not required to perpetuate the reaction. They may be absorbed nonproductively in structural materials, in the fission fragments, in control materials within the fuel assembly, in the reactor or in the reactor coolant. They may also escape from the reactor via absorption into the surrounding shielding material.

To be operationally successful, for every neutron absorbed by an atom of fissionable material, more than one of the excess neutrons must be absorbed in fertile material to create more than one new atom of fissionable material. If only one atom of new fissionable fuel is produced per atom consumed, the amount of fuel remains constant and breeding barely occurs. If the breeding ratio = 1.0 the gain = 0.

In breeding, the average number of neutrons released in fissioning must be greater than two; one is required to continue the fission process, and slightly more than one is needed to convert fertile material into new fissionable fuel. This means that breeding may be possible if more than two (+ captures) neutrons are produced; but if two + C, or less, are produced, breeding cannot occur.

Breeders utilize either uranium or plutonium fuels and, at the same time, convert Th232 or U238 into fissionable U233 or Pu239, respectively. In the conversion process, a neutron is captured by the nucleus of a fertile atom, and betatrons (beta particles) are released. The Th232 - U233 cycle is feasible only in a so-called thermal reactor in which neutrons are slowed by collisions with a moderator to energies of about 1 mile per second, or .05 electron volts.

All reactors contain both thermal and fast neutrons, but engineer - designers select materials and arrangements that support the process desired. A fast reactor is one in which the amount of moderator material is so small that the fissions are caused principally by fast neutrons.

In addition to the fact that fission by fast neutrons produces a relatively large number of free neutrons, fewer fast neutrons are absorbed parasitically by breeder structural materials and reactor coolants. Breeder reactors using Th232 and U233 as fertile and fissionable fuels can use either thermal or fast neutrons. Breeder reactor units using U238 and Pu239 must be designed for fast neutron reactions.

The breeder reactor core and fuel placement matrix are designed to achieve the greatest possible neutron capture rate in fertile material. For example, when U238 captures a neutron, a heavier isotope, U239 is formed. This isotope is unstable and disintegrates by emitting a beta particle. Since the proton number increases by one, the new material formed is an isotope of neptunium (Np239).

This isotope is also radioactive and disintegrates by emitting a beta particle with the end product, Pu239, a suitable nucleus for a reactor fuel. The sequence of events leading to the production of Pu239 from U238 is shown below. A similar breeding process can be developed using Th232 as the fertile isotope to produce fissionable U233.

Step 1 - The formation of ^{239}Pu starts with ^{238}U capturing a fast neutron to form ^{239}U.
$$n_f + {}_{92}^{238}U_{146} \rightarrow {}_{92}^{239}U_{147}$$

Step 2 - This is followed by the B^-decay of ^{239}U to ^{239}Np.
$${}_{92}^{239}U_{147} + B^- \rightarrow {}_{93}^{239}Np_{146}$$
Half-life = 23.5 min.

Step 3 - Finally, ^{239}Pu results from the B^-decay of ^{239}Np.
$${}_{93}^{239}Np_{146} + B^- \rightarrow {}_{94}^{239}Pu_{145}$$
Half-life = 2.35 days

Breeding ratios and doubling times are measures of the fuel efficiency of a breeder reactor. The "breeding ratio" is the number of atoms of fissionable material produced per atom of fissionable material consumed. "Doubling time" is the period required for a breeder reactor to produce as much fissionable material as the amount contained in its core plus the amount tied up in the fuel cycle. Doubling time, then, is a measure of the amount of breeding per inventory that is achieved in a given design. The more fissionable material produced within a given period or the lower the inventory by breeding, the shorter the doubling period.

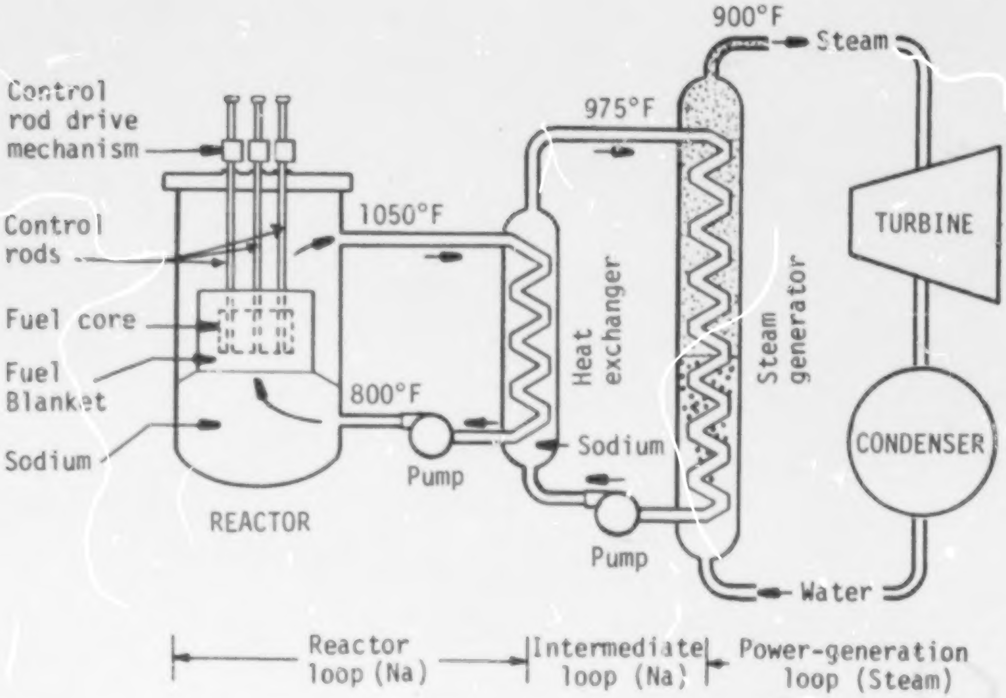
The production of excess fissionable material in the reactor is not the whole story however. Periodically, fuel elements have to be removed, partly because element containers do not last indefinitely, but mainly because fission products build up and reduce reactivity. The fuel must then be chemically processed. Processing is required to recover unused fissionable materials and to "cleanse" the fuel. This cleaning removes the accumulated fission fragments which reduce the productivity of capture. Once recovered, the fissionable material can be made into new fuel elements that are loaded back into the reactor to continue the power generating and breeding process.

Types of Breeder Reactors

Both in the United States and abroad, primary effort at developing breeder reactors has been directed to those using plutonium as a fuel and liquid sodium as a coolant. This type, termed the liquid metal fast breeder reactor (LMFBR), is the highest priority U.S. civilian power reactor development. The basic arrangement of an LMFBR nuclear steam unit is shown in Figure 16-1.

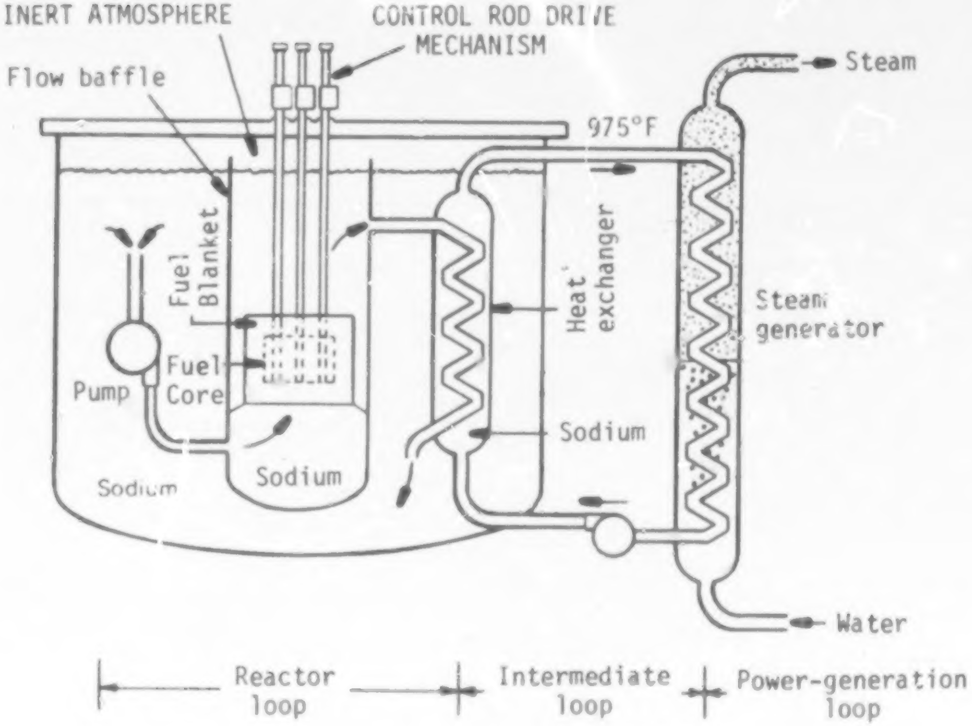
As the figure demonstrates, there are three basic loops in a power generating unit utilizing an LMFBR. In addition to the power generation steam loop, there are the reactor sodium loop and the intermediate sodium loops. In both the reactor loop and the intermediate loop, the fluid is liquid sodium. Sodium possesses excellent heat transfer properties and its 895°C boiling point allows the system to be operated at low pressures. An advantage of liquid sodium is its ability to cool by natural circulation in the event of an emergency shutdown.

Figure 16-1


900°F
Steam
Control rod drive mechanism
975°F
Control rods
1050°F
TURBINE
Fuel core
Fuel Blanket
Heat exchanger
Steam generator
800°F
Sodium
Sodium
Pump
CONDENSER
REACTOR
Pump
Water
Reactor loop (Na)
Intermediate loop (Na)
Power-generation loop (Steam)

LMFBR nuclear POWER UNIT SCHEMATIC

Figure 16-2


INERT ATMOSPHERE
CONTROL ROD DRIVE MECHANISM
Flow baffle
Steam
975°F
Fuel Blanket
Heat exchanger
Steam generator
Pump
Fuel Core
Sodium
Sodium
Sodium
Water
Reactor loop
Intermediate loop
Power-generation loop

Pot-type LMFBR SCHEMATIC

In the primary loop, the sodium* reaches the reactor core at a temperature of about 800°F. The sodium flows through the core where its temperature is raised to about 1050°F. It then passes through the heat exchanger where the sodium in the intermediate loop absorbs the majority of the heat added. This transfer of heat from the reactor loop to the intermediate loop reduces the temperature of the sodium in the reactor loop so it can be pumped back through the reactor and the cycle repeated.

The sodium in the intermediate loop is heated to approximately 975°F. It then passes through the steam generator and is returned to the heat exchanger. In the steam generator, the intermediate loop sodium heats the water of the power generation loop and produces steam at about 900°F. The intermediate loop is a safety feature of the LMFBR. The loop separates the radioactive loop from the power generation loop, minimizing the risk that a single leak could introduce steam into radioactive sodium or that a chemical reaction would occur between the radioactive sodium and the water or steam in the power generation loop.

---

*Sodium as a coolant possesses several desirable features. Although it is a metal at low temperatures, it melts at 210°F, a temperature sufficiently low to permit ease of maintenance and preheating under conditions where the sodium must be removed from the unit.

Since the maximum operating temperature in the core will approximate 1100 to 1200°F, it is not necessary for the sodium to be maintained under pressure. Pumps and piping need possess only sufficient strength to confine the liquid sodium on its route through the reactor pumps, steam generators and associated piping. Elimination of the need for pressurization removes much of the concern and engineering challenge associated with the need to hold high pressures on the primary and secondary systems.

The ability of liquid sodium to conduct heat is excellent and it achieves heat transfer with the minimum of moderation of fast neutrons required to sustain the neutron reactions because so little of it is required. The fission fragments that do escape from the fuel rods and leak into the liquid sodium can be readily tied up chemically and removed from the system so that they do not present immediate environmental hazards.

Sodium in liquid form will oxidize and burn if exposed to the air, and it reacts violently if exposed to water, producing hydrogen in the process. While liquid sodium appears to present an ideal solution to transferring the heat generating within a core, precautions must still be observed if adequate environmental protection is to be insured.

The core of a typical LMFBR consists of a central region of fissionable material mixed with fertile material. The fuel sustains the chain reactions and produces a surplus of neutrons that can be absorbed in the blanket fuel material. The core consists of thousands of small vertical rods arranged so that the sodium coolant can flow among them and remove the heat generated.

The fissionable and fertile materials are bound in ceramics able to withstand high temperatures. To protect the ceramics from possible damaging action by the flowing sodium, the fissionable and fertile materials are encased in thin tubes of stainless steel. The fuel tubes form rods that are about the diameter of a pencil and are several feet long. The best developed forms of fissionable and fertile materials used in LMFBR's are oxides, but carbides and nitride forms are also under consideration.

The plutonium-uranium system is used in LMFBR's, and the materials involved are plutonium dioxide and uranium dioxide. With a reactor fueled and ready for operation, the fuel portion of the core consists of a mixture of the oxides of Pu239 and U238, while the blanket contains the oxide form of U238. The normal initial content of the oxide mixture is about 20% plutonium and 80% U238.

Interspersed within the core are control rods made of such materials as cadmium or boron which function as neutron "blotters". By changing the degree of insertion of the control rods in the core, either a smaller or greater number of neutrons can be made available; thus, the control rods function precisely as they do in light water reactors by controlling or regulating the neutron flux available within the core area.

Despite considerable effort in the U.S. toward development of LMFBRs, extensive disagreement exists concerning the viability of the LMFBR concept. Critics point out that plutonium can be misused. Additionally, the sodium must be kept extremely pure because small amounts of impurities can obstruct flow and cause a core "disassembly" accident (nuclear excursion).

A second type of LMFBR is the "pot-type" system. The arrangement illustrated in Figure 16-2 is designed to overcome some of the disadvantages associated with the three-loop LMFBR system discussed previously. Advantages and disadvantages exist with both concepts. For example, the pot-type system is more compact, and its core can be cooled more easily if pump failure occurs. Despite some drawbacks, the LMFBR appears to be one of the more advanced of the breeder types on which research is presently being conducted.

The compactness of the core in breeder reactors, and the high flux densities within the core area, mandates the need for breeder reactor fuels and fuel pins able to withstand extremely high rates of neutron radiation for long periods of time, periods of time sufficient to permit fission of 10% to 12% of the heavy atoms. This is in comparison to 2% of the U235 in LWR's.

Research today suggests that the heavy flux densities and fast neutrons in the cores of breeder reactors have important effects on the stainless steel used for the structural material of the reactor itself and on the material used for the fuel rods. Radiation damage in steel tends to create small voids that cause the material to swell or become brittle and subject to fracture.

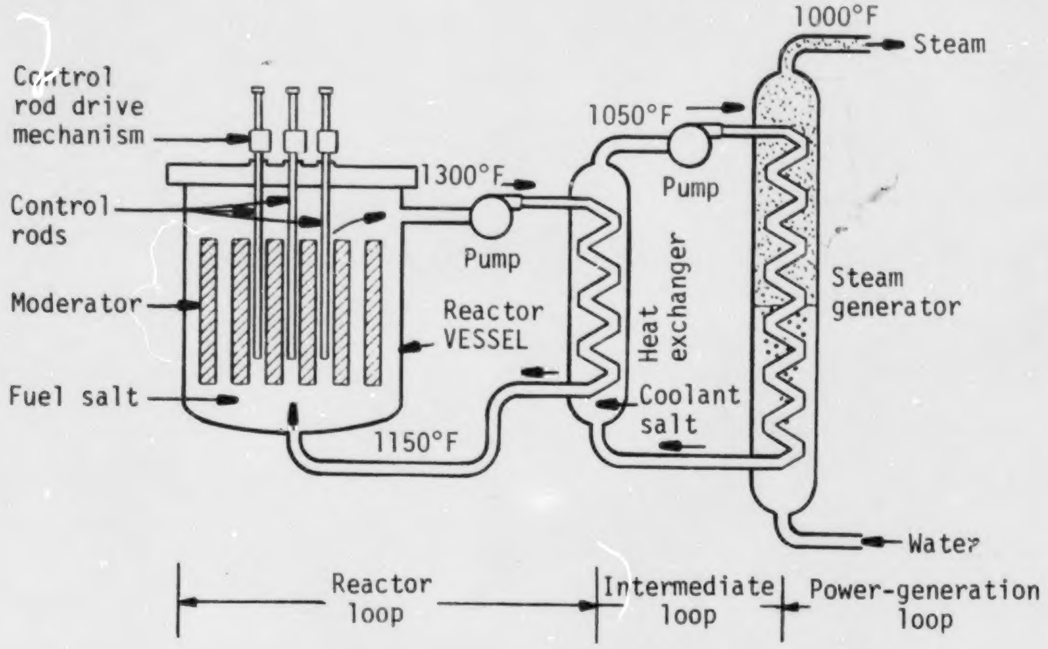
Considerable data exist on the amount of swelling that is expected to occur at high neutron flux levels expected in commercial-size LMFBR's, and NRC scientists suggest that the volume changes may be as high as 10%. The volumetric increase in localized areas represents yet another area of reactor research into which additional funds must be directed.

The gas cooled fast breeder reactor (GCFBR) has been under study in the U.S. since the early 1960's. Figure 16-3 shows that the GCFBR bears some resemblance to the pot-type LMFBR. The system is a closely coupled unit in which the reactor coolant fluid is circulated within a single large vessel. Actually, the resemblance between the two kinds of breeders end there.

The GCFBR uses helium as a coolant fluid. Although helium is not as good a heat transfer agent as liquid sodium, it does not become radioactive and no intermediate steam generator is required. But because the heat capacity of a gas is much smaller in terms of thermal conductivity than that of a liquid metal, the gas must be compressed to high pressures, i.e., 70 to 100 atmospheres, with the entire reactor enclosed in a gas-tight high pressure vessel (one atmosphere equals 14+ pounds/in^2).

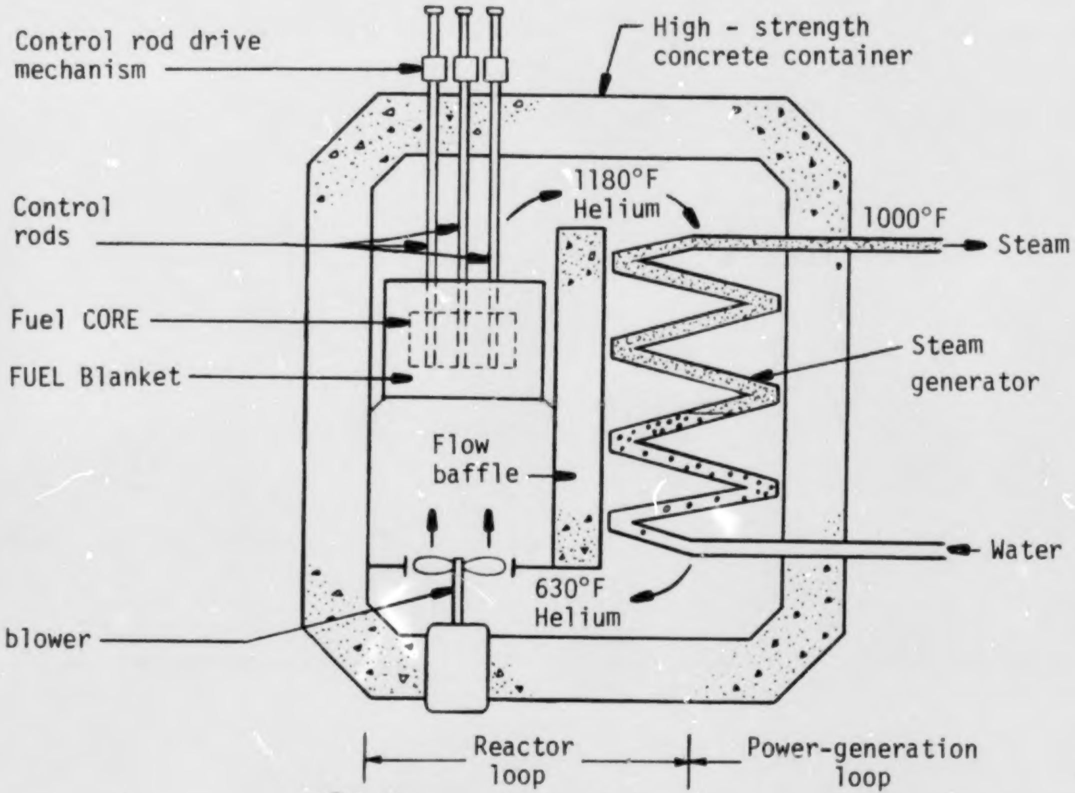
Under high pressure and high velocity conditions, the gas is effective in removing the heat produced by the nuclear processes within a core. Early designs for gas cooled breeders were based on the assumption that extremely high temperatures would be required and that elaborate safety precautions would be necessary. The development of high strength prestressed concrete vessels has eliminated some of the safety concerns as well as some of the expected high cost. The possible advantages of gas cooled breeder reactors are numerous.

Figure 16-4


1000°F
Steam
Control rod drive mechanism
1050°F
1300°F
Pump
Control rods
Pump
Moderator
Reactor VESSEL
Heat exchanger
Steam generator
Fuel salt
Coolant salt
1150°F
Water
Reactor loop
Intermediate loop
Power-generation loop

MSBR SCHEMATIC

Figure 16-3


Control rod drive mechanism
High - strength concrete container
1180°F Helium
1000°F
Control rods
Steam
Fuel CORE
Steam generator
FUEL Blanket
Flow baffle
Water
630°F Helium
blower
Reactor loop
Power-generation loop

GCFBR SCHEMATIC

One of the most significant expected advantages is the high fissile production rate (breeding gain). 1 GCFR can fuel 3 HTGR's, and, therefore, fewer breeders are required (compared to building 4 LMFBR's). 6 CFR's are plumbed to produce both Pu and U-233. Since helium absorbs fewer neutrons than sodium, there is less neutron moderation. Some scientists believe that a doubling time of less than 10 years may be possible. Helium does not become radioactive and if leakage should occur, it does not react with air or water. Helium does not void and cause core disassembly accident concerns.

A major disadvantage of gas cooled breeder units is the high operating pressures required to maintain circulation and cooling. In the event of a reactor accident in the coolant system, the gas cooled reactor must depend on high capacity mechanical equipment to circulate the gas, and it must be extremely reliable equipment. Some of the problems associated with the "swelling" of the fuel elements and internal components of the LMFBR also exist in the GCBR.

Molten Salt Breeder Reactor

This is the third of four types of breeder reactors currently under development. The MSBR doesn't use conventional fuel elements and, like the others, is a concept of American origin and evolution.

When the U.S. started work on nuclear powered aircraft in 1947, the molten salt reactor was among the systems considered for the power plant. Although the airborne reactor never materialized, the molten salt reactor did. The successful operation of an experimental molten salt reactor, coupled with major research and development that make possible a relatively simple unit, has led to the molten salt breeder reactor shown schematically in Figure 16-4.

The schematic shows that the MSBR is not unlike the LMFBR. Each possesses a reactor loop, an intermediate loop and a power generation loop. The molten salt breeder reactor is expected to operate at very high temperatures requiring special materials. However, its compact size and the small amounts of fuel required are expected to result in relatively low capital requirements with extremely long doubling periods for fuel generation.

The basic concept of the molten salt breeder reactor is one in which fissionable material and fertile material are circulated in liquid form through a region where the fission process can occur. The fuel is a liquid combination of four fluorine-salt compounds, lithium, beryllium, thorium, and uranium fluorides. The configuration of fissionable materials plays an important role in the fission process. For example, chain reactors do not take place easily in thin sheets of fissionable material regardless of size.

As long as the molten salts are confined to a narrow channel, no chain reaction is possible in the MSBR. However, as the liquid is pumped through hundreds of parallel channels in a graphite framework within a core, it assumes a mass similar to that of a conventional solid fuel reactor unit and a self-sustaining chain reaction can occur. The MSBR is, then, a thermal breeder.

In considering the MSBR, it is important to note that no chain reaction can exist outside the core. Operationally, heat is produced as the salt flows through the core region where it momentarily becomes or functions as the core and generates heat as part of the fission process. When a particular unit of molten salt leaves the core, the reaction within that specific unit stops. The salt then becomes the circulating fluid that transports the heat from the reactor to the heat exchanger.

Advantages or disadvantages of the MSBR include the possibility of on-site fuel reprocessing and associated licensing and economic problems, the elimination of the need to fabricate the fuel into precise containers, and the ability to provide, on a continuous basis, the chemical treatment required to remove undesirable fission products.

Drawbacks to the MSBR include the fact that the fuel produces energy only while it is inside the core. A utility company operating on MSBR would have to buy enough fuel not only to fill the core but also to fill all the external piping that leads to the steam generator. Additionally, molten salts pose an unsolved engineering problem because the high corrosivity of the fission product, tellurium, on the reactor vessel.

Environmental Aspects

Positive and negative aspects of each of the breeder reactor types have been noted. However, a few additional comments seem to be in order. Breeders use fuels which are highly enriched, making them a possibly more tempting target for thefts or sabotage. Larger quantities of plutonium would be involved, both as a product of the breeding process and as a direct result of the fuel loads used in the breeder reactors. Because fast breeder reactor cores must be highly compact if maximum output of the fast neutrons is to be realized, the possibility of achieving what is called "secondary criticality" must be recognized.

Primary criticality, which is basic to the operation of nuclear fueled units, is attained only after the neutrons have been slowed or thermalized. If the coolant, which also acts as a moderator in a LWR, is accidentally removed, the moderating mechanism is also removed and the chain reaction stops.

However, in the case of LMFBRs, loss of the sodium removes only the coolant and has little effect on the conditions necessary for criticality, i.e., even with the sodium removed, a chain reaction would continue.

If a sudden meltdown of the core occurred in an LMFBR, some scientists believe that the core components could melt and assume a different geometric arrangement. This rearrangement, they believe, could result in a critical mass which could produce an uncontrolled chain reaction. This is "secondary criticality." Prevention of this possible danger has played an important role in the design of all FBR's.

On the positive side, breeder reactors can achieve much higher efficiencies because of the higher temperatures utilized. And higher efficiencies mean less thermal pollution, a factor which many deem to be of overriding importance. Not to be overlooked is the strong possibility that thorium may well prove to be the fuel of the future in breeder reactors.

Finally, if the problems described are resolved, it is clear that higher breeder fuel efficiencies, and the broader spectrum of fuels which the units can use, hold the promise of extending domestic nuclear fuel supplies by many orders of magnitude. And as nuclear fuel use is extended through breeder reactors, the need for more-and-more expensive exploration and mining of other fuels can be reduced.

The fact that breeder reactors hold such high promise for using nuclear fuels more efficiently suggests that major research effort should continue to be expended on this power form. Scientists working on breeder reactors have already made great progress. But, as they point out, although the dream exists, there are still substantial voids or gaps to fill in the development and harnessing of this technology.

CHAPTER 17

FUSION

Some very knowledgeable people believe that controlled thermonuclear fusion will be the ultimate solution to the world's energy problems. Other equally well informed scientists hold opposite and contrasting views. Despite the dichotomy noted, it is apparent that with the exceptions of the various forms of solar energy and fission breeders, fusion energy alone possesses the advantages of wide spread fuel availability and essentially unlimited low-cost fuel supplies.

Deuterium (^2H or ^2D), one of the two basic ingredients utilized in low temperature fusion (100 million degrees K), exists in water in the ratio of 1:6000. Tritium, (^3H or ^3T), the second fuel component, can be produced in adequate quantities as part of the fusion process via neutron activation of ^{6}Lithium ($n + {}^6Li \rightarrow {}^3T + {}^4He$).

Evidence that nuclear fusion can be achieved has been obtained from laboratory experiments. Deuterons, or deuterium nuclei, can be accelerated to high velocities in a charged-particle accelerator such as a cyclotron. If such deuterons are allowed to strike a solid target containing deuterium, fusion reactions occur.

In the early stages of the atomic age, scientists realized that if the reactions responsible for producing a hydrogen bomb could be controlled, an energy source of truly fantastic dimensions might become available for man's use.

As early as 1920, the English astronomer, Arthur Stanley Edington, speculated that the sun's energy might be derived from the interaction of subatomic particles. Some sort of nuclear reaction seemed to be the most reasonable way of explaining the vast energies constantly being released by the sun. Edington's study of the structure of the stars produced convincing theoretical arguments that temperatures at the center of the sun are enormous, approaching 15 to 20 million degrees C.

At such temperatures, atoms could not exist in the fashion known to us. Held together by the sun's strong gravitation field, the atoms collided with such high energies that all or almost all electrons were stripped and little more than bare nuclei remained. These bare nuclei, smashing together at center-sun temperatures, could fly apart and be rearranged to form more complex nuclei in collisions labelled, "thermonuclear reactions."

Later studies have suggested that the structure of the sun is primarily one which is rich in hydrogen. If such is the case, the release of the energy from the sun must be the result of hydrogen fusion. Calculations based on the high rate of solar thermonuclear reactions suggest that roughly 650 million tons of hydrogen are converted into helium every second, and in the process, the sun is reduced in mass by about 4,600,000 tons per second.

In the early 1950's, theory strongly suggested that the technology for harnessing the power of thermonuclear fusion could be achieved in a relatively short period. However, scientists did not realize that controlled thermonuclear fusion would require development of a completely new field of science, plasma physics, and that ground-breaking research would be needed on how to contain plasmas at temperatures many orders of magnitude higher than any yet achieved in a controlled environment. Research has demonstrated that while fusion is a leading contender as our major future energy source, serious obstacles must yet be overcome. Let's examine the requirements for controlled fusion.

The Basics of the Fusion Process

The majority of fusion research over the last two decades has been directed toward "magnetic plasma" containment; in more recent years, "laser fusion" has achieved significant and encouraging results. Although the objectives of the two approaches are identical, their technologies differ significantly. Since the greatest effort and money have been directed to magnetic containment, let's examine those systems first.

For fusion to occur, two light nuclei must first come close enough to interact. Since each nucleus carries a positive electrical charge, the two nuclei repel with increasing force as they come closer together. For the nuclei to interact then, they must have enough energy to overcome the electrostatic force which tends to separate them.

Since the magnitude of the repelling force increases with the electrical charges on the nuclei, ideally, the interacting nuclei should have the lowest possible charge or atomic number. The element with the smallest atomic number is hydrogen. H nuclei, and those of its isotopes 2H and 3H, carry but one charge. The obvious choice for fusion fuel, then, is some form of hydrogen.

A second advantage is the fact that hydrogen is abundant and relatively inexpensive. Three isotopes of hydrogen are known. The lightest is ordinary hydrogen (H) with a mass number of one. The second isotope is deuterium (2H) with a mass number of two, and the third isotope, tritium (3H) has a mass of three. The nucleus of an atom of the common hydrogen isotope (H) is called a proton, the nucleus of 2H is a deuteron, and the nucleus of 3H a triton. Tritium (3H), while rare in nature and radioactive, can be manufactured through the interaction of neutrons and lithium 6.

Although a number of possible fuel combinations hold promise, the prime candidate for fusion reactions will be deuterium-tritium because its ignition temperature (100 million degrees C.) is low and the reaction rate is high. The advantages of the D-T reaction are offset in part by the possibility that volatile and radioactive tritium could be released into the environment.

Although tritium has a relatively short half-life, 12.3 years, its characteristics would permit rapid distribution through both the atmosphere and hydrosphere. The low-energy beta emissions of tritium are relatively benign compared to radioactivity of other fission products. This advantage, however, is offset, in part, by anticipated difficulty in containment.

Although fusion with either deuterons or tritons may occur, deuterium would be an ideal fuel because of its low cost and availability. Two D-D reactions occur roughly equal probabilities as indicated:

1. ${}^{2}D + {}^{2}D \rightarrow 3\ \text{Helium} + 3.2\ \text{MEV} + n$
2. ${}^{2}D + {}^{2}D \rightarrow {}^{3}T + H + 4.0\ \text{MEV}$

In the first reaction, the products are a ${}^{3}He$ nucleus, a neutron and energy. In the second, a triton, hydrogen nucleus and energy release result. The triton (T) formed in reaction 2 reacts with another deuteron (D) to produce helium 4, a neutron and a large energy release, i.e., $T + D \rightarrow {}^{4}He + {}'n + 17.6$ MEV. The net energy release for the fusion of five deuterons is 3.2 + 4.0 + 17.6 MEV for a total of 24.8 MEV! A schematic of the fusion reactions involving deuterium and tritium is shown in Figure 17-1.

To produce controlled thermonuclear energy, scientists agree that these six conditions must be present:

1. Ignition temperatures above 100 million degrees C for D T reaction.
2. Containment and compression of the high temperature plasma.
3. Maintenance of plasma compression and ignition temperatures under conditions which permit energy production to exceed energy losses.
4. Injection of fuel to perpetuate the reaction.
5. Extraction of the energy.
6. Confinement time (t seconds) and particle density (nm^{-3}) yielding a product n^{t} of 10^{21} or greater.

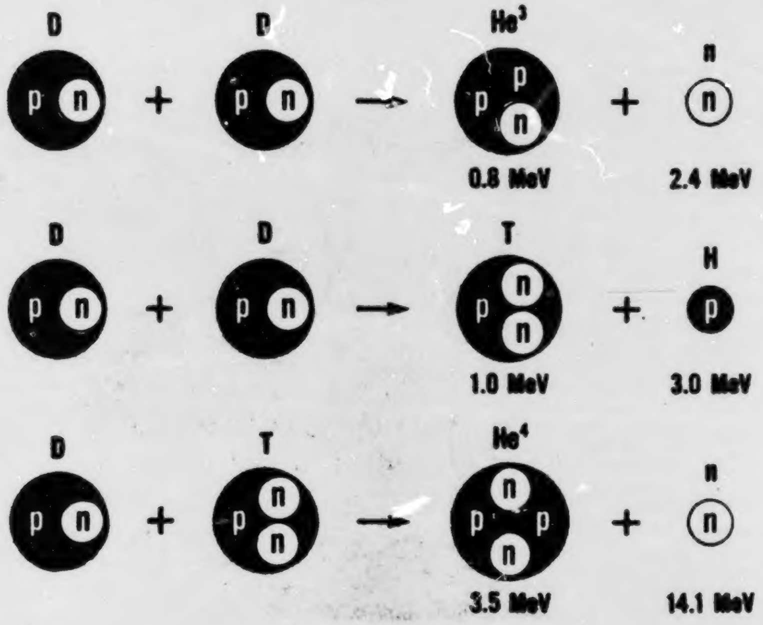
Magnetic Containment Systems

Since these conditions have not been necessary in conventional energy systems, controlled thermonuclear fusion represents an entirely new order of technological challenge to scientists.

The temperatures needed to fuse tritium - deuterium or deuterium - deuterium are so high that no known materials can contain the plasma without quenching the contained materials. Many scientists believe that magnetic fields can successfully be used for containment, and over the past two decades the majority of the development work in both the USSR and the U.S. has been directed toward toroidal, magnetic containment devices.

A number of systems, referred to as "magnetic bottles," based on the use of superconducting magnets to create forces on the charged particles in the plasma, have shown promise. The theory of magnetic containment is as follows:

Figure 17-1


D
D
He³
n
p
n
p
n
p
p
n
n
0.8 MeV
2.4 MeV
D
D
T
H
p
n
p
n
p
n
n
p
1.0 MeV
3.0 MeV
D
T
He⁴
n
p
n
p
n
n
n
p
p
n
n
3.5 MeV
14.1 MeV

Fusion reactions with deuterium (D) and tritium (T) nuclei. Fusion energy is divided between the products as noted.

When sufficient force is applied perpendicular to the trajectory of a charged particle, the particle will assume a circular path, or orbit. Within a magnetic containment fusion reactor, a plasma particle thus trapped travels in an orbit defined by the lines of the magnetic fields. The strength of the magnetic field directly influences the maximum velocity and density of the plasma particles which can be held by the field.

Only recently have the pressures and temperatures required to sustain the fusion process been achieved to a degree which suggests that the efforts may possess viability.

At temperatures up to 1 million degrees Kelvin, a deuterium or deuterium--tritium plasma can be heated by passing an electric current through it. This process, termed resistance heating, depends solely on the resistance of the medium conducting the flow of current. Unfortunately, the process disintegrates in a fusion reactor, because as the temperature increases, the resistance of the plasma decreases, eventually becoming too low to function effectively.

An alternate procedure for heating the plasma within a magnetic containment unit involves the sudden compression of the plasma by increasing the strength of the magnetic field forming the container wall. If a number of successive stages of magnetic compression are employed, very high temperatures can be attained. The 100 million degree K. temperature required for D-T fusion has been pursued by injecting and trapping particle beams in "magnetic marrors." Despite the progress cited, some scientists doubt that magnetic fusion will ever be possible. Plasma containment is the major barrier. If the heated plasma contacts the cooler wall of the structure, it cools, loses energy and the fusion process stops.

A major problem in compression heating has been to achieve balance between the outward pressure of the plasma and the inward magnetic pressure. At the junction of the two areas near the edge of the plasma, instability occurs and the magnetic lines become badly tangled. One consequence of this "plasma confusion" at the periphery of the plasma field is the loss of plasma through leaks. A donut-shaped magnetic bottle (toroidal design) represents one of the advanced efforts to control plasma leakage (see Fig. 17-2).

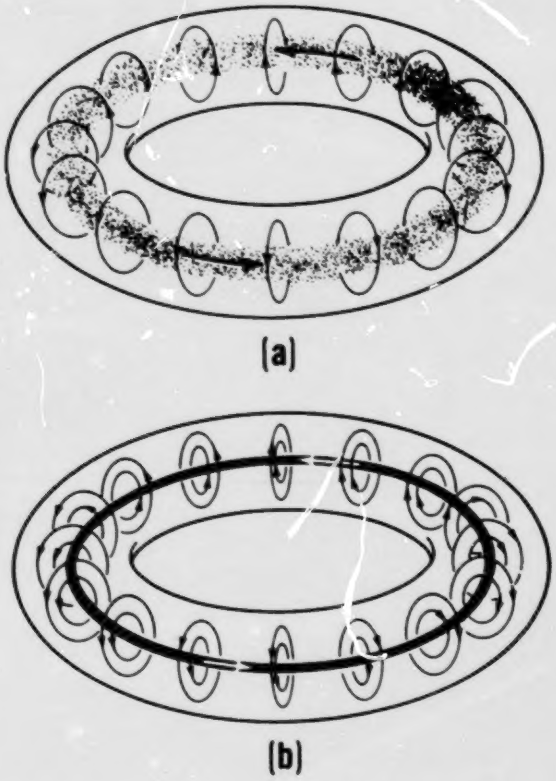
At fusion temperatures, radiation also becomes a source of energy loss. Bremsstrahlung radiation, similar to X-rays, occurs when the charged electron drops into lower energy states. Cyclotron radiation, via losses in the infrared and microwave region, also occurs. While much of this energy can be reabsorbed by the plasma, some of it leaves the reactor and is lost as a source of heat. Overall, these radiation losses are not expected to be a serious problem for D T and He3 fuels.

Plasma Containment

Plasma, like a normal gas, exerts a pressure that is proportional to its temperature and particle density. In effect, a confining magnetic field exerts an inward pressure which, in the ideal situation, balances the outward pressure of the plasma particles. Since the strength of magnetic fields is limited and since magnetic fields cannot be constant and still meet other confinement requirements, there is a limit to plasma pressures produced.

A controlled fusion system will require a plasma density-time product of 10^{14} particles per cubic centimeter, i.e., 10^{15} for 1 sec. At the temperatures which must be developed in a fusion reactor, a particle density of 10^{15}/cc represents a pressure in excess of 1000 pounds per sq. inch. It is that magnitude of pressure which must be contained within the magnetic field!

Figure 17-2



Representation of the pinch effect in a toroidal tube; (a) shows the beginning of the discharge and (b) the fully formed pinch. The dark rings are the plasma in which an electric current is induced; the circles surrounding the plasma indicate the magnetic field produced by the current.

Evidence to date suggests that after 20 years of research in this country and abroad, the requirements for developing a controlled fusion reaction via magnetic containment devices have not been realized. Although truly significant achievements have resulted, magnetic containment fusion as a practical contributor to U.S. energy needs will not likely make an impact in this century.

Laser Fusion

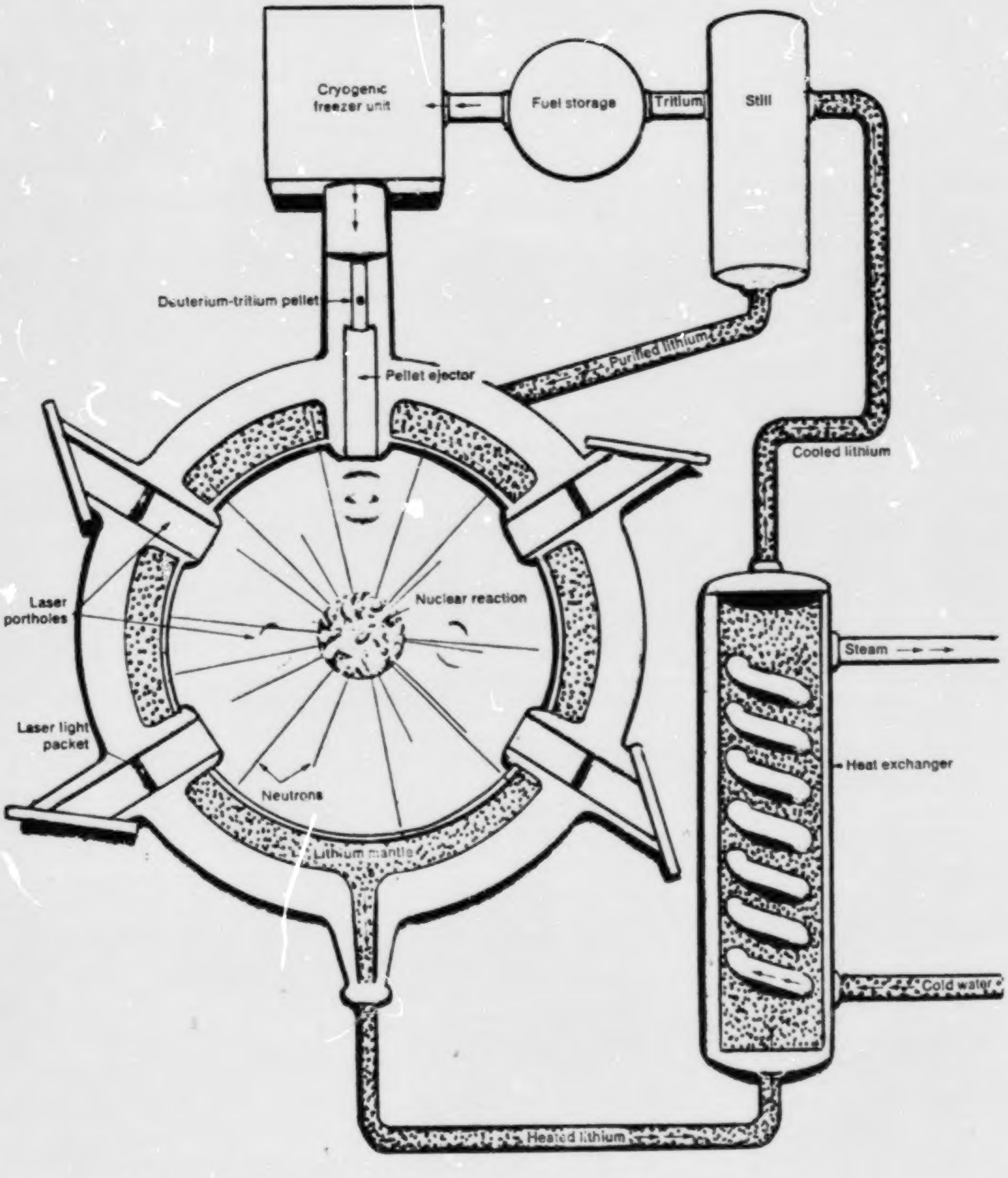
The many difficulties of magnetic confinement systems have led some researchers to seek other solutions to the challenges of controlled fusion. After researchers in the U.S.S.R. announced in 1968 that a laser beam could initiate a fusion reaction, many countries either began or expanded laser fusion research programs.

Laser function research has thus far been examined largely through computer simulations. Through experiments, however, yields of 10^6 neutrons have been realized. If models are correct, laser units under construction in the U.S. and other countries could demonstrate the scientific feasibility of the laser principle within the next decade. ("Laser" is an acronym derived from the first letters of the words, Light Amplification (by) Stimulated Emission (of) Radiation.)

In theory, laser fusion involves focusing multiple beams of electromagnetic radiation on a solid D-T pellet about 1 millimeter in diameter. The laser energy heats the pellet via compression to ignition temperatures of 100 million degrees K. +). The combination of high temperature and enormous density triggers a fusion reaction.

Some laser fusion reactor proposals envision a blanket of liquid lithium around the combustion chamber to absorb neutrons and to act as a heat transfer medium. Refer to figure 17-3.

Figure 17-3


Cryogenic freezer unit
Fuel storage
Tritium
Still
Deuterium-tritium pellet
Pellet ejector
Purified lithium
Cooled lithium
Laser portholes
Nuclear reaction
Steam
Laser light packet
Heat exchanger
Neutrons
Lithium mantle
Cold water
Heated lithium

FORTUNE *May 1974*

Confinement

Although a significant number of engineering problems must be overcome before the first laser fusion unit can become operational, one of the most significant and complex challenges is to design and construct a container strong enough to accommodate the powerful D-T reactions required. Spherical vessels of steel or other materials can withstand relatively small explosions (equivalent to 500 lbs. of TNT) which is much less than the individual micro-explosions in power reactor conceptual design studies.

Additionaly, a method must also be found to contain the liquid lithium used as a neutron absorbent and coolant if that method is used, and to protect the fusion reactor from radiation damage. Laser reactor feasibility studies conducted at the Los Alamos Scientific Laboratory indicate the problem may be solved by using a double-walled vessel with the liquid lithium circulated between the walls. Feasability? An apparent "yes"! Ease of achievement? An obvious "no"!

Fuel Implosion

Examine next the process by which fuel is "imploded" in the fusion reaction. In a laser fusion unit, it appears that implosion pressures and temperatures may be high enough to permit more complete combustion than could be achieved in magnetic containment.

Imagine placing a frozen hydrogen pellet in the center of the spherical fusion unit where it can be bombarded by a powerful laser impulse. If the pellets could be injected at a rate of 1 or 2 per second, the result would not be unlike what occurs in an internal combustion engine where each cylinder contributes a given fraction of energy (except the instantaneous power levels would be astronomical).

In the early 1970's, a concept for using multiple laser units to bombard a hydrogen pellet was advanced. Essentially, the process would allow the pellet to be struck simultaneously with multiple laser beams rather than with just one. A group at the Lawrence Livermore Laboratory, using computer simulation, theorized that multiple laser bombardment would instantly vaporize a shell of the D-T pellets and cause them to implode with enormous force.

In keeping with Newtonian Law (every action produces an equal and opposite reaction), vaporization would initiate an implosion toward the center of the pellet and compress its inner core dramatically, to a density around 100 times that of lead.

This suggests that multiple laser techniques may present a major advantage, because fusion reactions are dependent not only on temperature but also on the density of the plasms. The greater the density achieved, the lower the quantity of heat required to initiate the fusion reaction. Calculations by the Livermore group indicate that compressive implosion may permit fusion with 100,000 times less laser energy than was estimated in earlier studies.

Laser technology, or perhaps the lack of it and achievement of pellet energy gains are the primary stumbling blocks to the development of laser fusion devices.

Laser Ignition

Laser energy is composed almost entirely of waves of the same length. If it were visible it would appear as a pure color. Also, laser radiation is coherent as opposed to the incoherent radiation associated with incandescent light bulbs. Both characteristics permit development and direction of extremely energetic laser radiation pulses. For example, the energy in a large laser radiation pulse may approach 1,000 joules with a pulse that exists for less than 0.1 (10^9) sec. This corresponds to an instantaneous power release of 10^{12} watts.

Impressive though these numbers may be, they represent only a small fraction of the energy required for hydrogen pellet ignition. During the early stages of laser fusion research, some scientists calculated that an effective laser would have to deliver 1.6 billion joules of energy in one one-billionth of a second (an output = to 300 million times that of Grand Coulee Dam). Since this was about 10 million times greater than the most energetic pulsed laser yet produced, the requirement was dizzying indeed. Lasers of the energy and rapid-fire capabilities believed necessary do not now exist, and discouragingly, technological breakthroughs which might serve to alleviate the dilemma are not evident.

The neodymium glass laser, although not capable of delivering the repetitive pulses desired, can make 2 or 3 powerful pulses an hour and represents a marked improvement over ruby lasers. In 1970, a group of physicists led by Professor Lubin, University of Rochester, succeeded in developing a laser pulse intense enough to heat a target to about 25 million degrees C., one-fourth of the way to the fusion temperature goal believed necessary, but at miniscube density.

Assuming that neodynium glass lasers can be improved, there remains the challenge that lasers operate at very slow rates of recharge. Physicists at both the Livermore and Los Alamos Laboratories calculate that not less than 1 laser cycle per second will be required for useful power unit.

One indication of the magnitude of the challenge is that the repetition rate of lasers in research conducted at the Naval Research Laboratory, one of the largest in the U.S., has been about one firing every four minutes.

Moreover, today's laser units are extremely inefficient. Typically, only about 0.3% of the electrical energy used to activate a neodymium glass laser unit emerges as radiant energy. More rapid firing rates and higher efficiencies are "must" priority objectives in laser research and development.

The Fuel Cycle

In the precise center of a power sphere, a frozen D-T pellet is struck simultaneously by a number of powerful laser pulses, instantly producing a small thermonuclear explosion. When the pellets are fed at a rate of at least one per second, a pulsing series of micro-explosions occurs, thus providing a continuous flow of high heat energy which is transmitted to the surrounding blanket of liquid lithium.

Each pellet, through ignition at about 100,000,000°K. turns momentarily into a miniature H-bomb in an intense thermonuclear reaction. Fusion transforms the hydrogen within the pellet into helium and releases energy in the form of neutrons and radiation.

As the neutrons are absorbed into the liquid blanket surrounding the inner chamber, the lithium is heated to approximately 1000°F. It is then pumped to a heat exchanger to produce steam for the generation of electric power.

Before recirculation, the lithium is routed through a separation unit where radioactive tritium created by neutron bombardment of the ^{6}Li is removed. The gaseous tritium is then processed, combined with the deuterium and made ready for subsequent introduction into the laser reactor.

It is estimated that the average reactor would contain approximately 100 million curies of tritium at any one time. This is comparable to the amount of radioactivity in the fission products of a breeder reactor. However, it should be noted that tritium emits only a low-energy beta particle and can be shielded with little difficulty. Containment of ^{3}H is difficult and represents still another challenge for those involved in laser fusion research.

What appears to be an ideal arrangement for the production of electrical energy from commonly available materials is limited by the scarcity of 6 Li. Lithium is not found in concentrated deposits but is distributed in trace amounts throughout most of the earth's crust. Lithium exists in reasonable quantities, with ^{6}Li constituting 7% of the lithium available.

If Laser fusion power generating units are to become a reality, procedures will have to be developed to reduce the amount of lithium required or production capabilities will have to be expanded.

Heat Extraction

The largest part of the energy released in D-T fusion appears as neutron kinetic energy. As in the fission process, a heat conducting material can be circulated around the hot plasma and pumped to a steam generator where the transferred heat is used to produce steam for direct use by a steam turbine. Aside from the initial heat absorption phase, the steam generation cycle in a laser fusion unit is much the same as in other thermal generating units.

Environmental Considerations

From almost every standpoint, fusion reactors appear to possess environmental advantages over fission and breeder reactors. Although both types of fusion reactors utilize deuterium and tritium, neither fuel element imposes an unwanted legacy of perhaps thousands of years of watchful maintenance over high level nuclear wastes.

Tritium is the primary fusion pollution problem. With a radioactive half life of 12.3 years and physical-chemical characteristics which make containment difficult, 3H may be introduced into the atmosphere where it is free to combine with moisture and fall to earth in either rain or snow. (One positive note -- fusion products would be extremely difficult to utilize in construction of bombs or explosive devices.) Biological studies indicate that the potential environmental hazards of tritium are only about 3% as great as those of plutonium used in breeder reactors.

One of the most significant potential contributions of fusion reactors to environmental protection is their potential to eliminate uranium and plutonium as fuels for power generation. Fusion reactors would make it unnecessary to store fuels which could be misused, would extend fuel supplies from a few decades to perhaps millions of years, and would make no demands on fossil fuels which have more productive uses and priorities.

The Future of Laser Fusion

The future of laser fusion as a significant contributor to the electrical generation needs of the U.S. is still unclear. For nearly two decades, the primary emphasis in fusion and laser research has been on military uses. Despite environmental advantages and the possibility that fusion reactors might be inherently safer than fission units, federally funded fusion research programs seem to be operating at low-levels.

Quite obviously, an impressively large number of barriers still exist to wide--scale fusion power generation. Feasibility of the fusion process remains unestablished. Advances are being made, but progress is slow. Fusion power, if developed, will likely come in large packages. Costs associated with construction, radiation protection, etc., suggest that the smallest economical units will be larger than 1,000 megawatts.

The evidence at hand indicates that the U.S. should continue its efforts to develops fusion based power generating units while recognizing the very real possibility that technological, environmental and economic barriers may prevent attainment of the goals sought.

CHAPTER 18

ENERGY CONSERVATION

> "I cannot say that I am in the slightest degree impressed by your bigness, or your material resources, as such. Size is not grandeur and territory does not make a nation. The great issue, about which hangs a true sublimity, and the terror of overhanging fate, is what are you going to do with all these things?"
>
> --Sir Thomas Henry Huxley
> Sept. 12, 1876

Sir Thomas Huxley made the above remark before dignitaries gathered at the opening of Johns Hopkins University. He added that 40 million Americans had witnessed the first centennial of the nation, and estimated 200 million would witness the second.

Huxley's visionary projection proved to be true.

If Huxley were on the scene today, he might well be bewildered at the polarization surrounding the word "conservation." In his somewhat imperious manner, he would no doubt pointedly tell us that energy conservation is no longer a choice. It is a necessity.

The sooner the American public accepts this, the better off we all will be. While conservation alone will not provide all the answers in our energy dilemma, a comprehensive energy conservation plan can help divert energy shortages within the United States.

However, achieving such a plan has proved anything but easy. In the United States only five percent of the average family budget has traditionally been spent on energy. That makes it difficult to generate a high-level popular concern over dour projections by a few "alarmists" in the energy field. A massive public education effort is required; one cornerstone of which must be the fact that there is no longer such an animal as cheap energy.

Another side of the conservation coin is the need to achieve increased energy efficiency in all areas of our activity. The United States, along with other industrialized nations, has a rather poor track record here. Bruce C. Netschert, vice-president of National Economic Research Associates, Inc., puts it this way:

> "We have tolerated physical inefficiencies in energy use that could have been rectified at any time, to our monetary benefit. In part, this has been due to ignorance, but in part also to the very cheapness of energy. With energy costs such a small fraction of personal budgets and of industry's total costs, we were sloppy in our energy use because it was just not worth the extra effort."

Critical shortages of natural gas, propane and heating oil during the coldest winter on record. A lingering drought in the western states. Mother Nature has managed to achieve what government, industry and conservationists failed to do --- bring home to the American people the fact that our energy problems are chronic, and that we must perform far better in our search for solutions. A consensus is emerging that the nation can achieve energy savings without sacrificing jobs, goods and services and without bankrupting the treasury to pay for important fuels.

Candidates for Energy Conservation

Transportation follows the industrial sector as the largest energy consumer. It accounts for 25% of total energy demand. It is also the largest user of petroleum -- consuming more than half of the petroleum used domestically. Obviously, because of the growing vulnerability of the U.S. economy to another embargo and the deteriorating international financial situation, energy conservation is particularly critical here.

There are three approaches to energy conservation in transportation. We must improve automobile fuel economy, shift traffic towards more efficient modes of transportation and increase load factors for existing transportation systems.

Clearly, the automobile offers the greatest potential for savings in the transportation sector -- 100 million cars consume 57% of transportation energy and account for 88% of passenger miles traveled. Unless conservation measures are enacted, the 1985 car population is projected to travel 24% further and consume substantially more fuel with little or no improvement in fuel economy (see Table I).

Significant fuel savings can be achieved through shifts towards lighter, more efficient cars, improvements in new car fuel economy and reductions in vehicle miles traveled (Table II). A shift towards smaller cars has been evident for some years. In 1958, 90% of new cars sold were standard size while the comparable figures for 1972 and 1974 were 38% and 35%, respectively. Recent projections indicate that by 1985, about 80% of new cars sold will be compact and subcompact with another 6% in the intermediate class. This would leave only about 13 to 14% in the standard and specialty categories. Thus, by 1985 the proportion of small cars in the total automotive fleet could grow from 24 to 62% and result in a savings of over 200,000 barrels of oil per day. (These projections, of course, do not reflect startling consumer preference for larger cars, mirrored in the marketplace in 1975 and 1976.)

New car fuel economy must also improve. Projections vary, but a target of 45% from 1975 to 1980 and a further 9% by 1985 is not unrealistic. This is slightly more ambitious than the voluntary goals set by the automakers, but still within boundaries established through federal studies. If these gains could be achieved, the savings would be 1.6 million barrels of oil per day.

Finally, there are savings possible through reducing automobile travel in urban areas and shifting traffic to mass transit. In 1972, 45% of all automobile travel occurred in urban areas. In order to reduce pollution and congestion, EPA has developed transportation control plans for 23 major polluted cities. These measures, i.e., bus only lanes, parking taxes, reduced mass transit fares and improved facilities -- are projected to reduce automobile use by 26% in these cities by 1985 and save almost 400,000 barrels of oil per day.

These three conservation measures will generate savings of 2.2 million barrels of oil per day by 1985. An additional 500,000 barrels of oil per day savings is possible through production efficiencies possible in building smaller cars, enforcement of the 55 mph speed limit, increased efficiency of intercity freight transportation and improved airline load factors. Thus, the total savings possible in transportation is in excess of 2.7 million barrels per day by 1985 as shown in Table III.

INDUSTRIAL

American industry, including agriculture, mining and manufacturing, consumes some 40% of total U.S. energy requirements. Based on what has happened since the oil embargo, we know that the industrial sector represents an important opportunity for energy savings.

The six largest energy consuming industries are pulp and paper, cement, food, metals, petroleum refining and chemicals. These industries consume 73% of manufacturing energy demand or 17% of total U.S. energy. Cement production and petroleum refining are the most energy intensive -- while metals are the largest consumers of energy as shown in Table IV.

It is clear that these industries must economize on energy now that energy prices have almost tripled, or they will lose markets to other products that are less energy intensive or to other manufacturers who are more conscious of energy costs and more efficient in their steps to reduce them.

The cement industry furnishes a useful example. A ton of cement costs about $25. Five dollars of this goes toward purchases of oil, gas or coal. Technologies are available to reduce the energy costs per ton by about 5% -- or to reduce the $25 price by about $1.25 per ton. And, in the highly competitive cement industry, the ability to reduce prices by 5% can be crucial in maintaining market share.

There are two major types of kilns in use today in the cement industry -- wet and dry. Conversion from a wet to dry kiln process can reduce kiln energy consumption by a million BTU/ton. In 1974, 59% of the industry's 445 kilns were wet process, 41% dry. Projecting future energy requirements, therefore, depends on the rate at which energy inefficient wet kilns can be converted to more efficient dry kilns.

Federal agencies, in close cooperation with the major companies in the six energy intensive industries, have developed projections of future industrial energy demand. A preliminary analysis suggests that these industries can reduce per unit energy usage -- beyond what was achieved in 1974 by 13 to 23% in 1985. The paper industry will do this through process improvements, phasing in new plants with increased energy efficiency and greater reliance on forest fuel as an alternate source. Other industries will improve energy management, increase maintenance, modify product mix specifications, and eliminate heating and cooling cycles which waste energy.

Whatever the method, the results can be impressive.

The six industries are projected to save 1.7 million barrels per day in 1985 and -- if these same results could be achieved throughout the industrial sector -- per annum energy growth would decline from 3.9 to 2.6% and yield savings of 2.8 million barrels per day in 1985. Table V shows these results.

COMMERCIAL

Commercial buildings consume 10% of all U.S. energy -- less than half that consumed by the residential sector. However, commercial space is projected to grow about 4% per year between now and 1985, and energy consumption is expected to grow at 5% (Table VI). In general, we would expect the commercial building owner to be more highly motivated to reduce energy consumption since he can pass along a portion of the costs to his customers.

It is difficult to project the percentage of the commercial market that can be backfitted by 1985 because of variations in building size, type of occupancy, quality of construction, and subsequent difficulty in installation. However, it is realistic to expect that 20% of the commercial market can be backfitted by 1985 -- about 4.8 billion square feet of commercial space -- with a resultant savings of 99,000 barrels of oil per day.

Reduction in energy needs of new commercial buildings could save 380,000 barrels per day and mandatory lighting standards an additional 150,000 barrels per day or a total of about 630,000 barrels per day for the commercial sector. Table VII shows these savings.

RESIDENTIAL

America's 70 million housing units consume 22% of all our energy. This breaks down as follows -- 57% for space heating and air conditioning, 33% for home appliances and 10% for lighting.

Table VIII shows that residential housing is projected to grow at 2% per year through 1985 and energy consumption at a slightly higher 2.5%. It is clear that this section must play a key role in a total energy conservation program.

The opportunities include backfitting existing homes with insulation, increased energy efficiencies in new homes, thermostat reductions, more energy efficient appliances and improved lighting standards.

Since existing housing will comprise almost 78% of the residential inventory in 1985, energy policies must focus first on this area. Given the proper financial incentives for people to install insulation and storm windows, and given the capacity of the fiberglass industry to expand, the nation should be in a position to backfit about 2% of existing homes per year between now and 1985, or about 18 million homes. Increased insulation, storm windows and doors, and improved weather stripping and caulking could save about 25% of current energy requirements. This translates into 230,000 barrels per day in 1985.

New homes have greater energy savings potential than existing homes since they can incorporate design improvements as well as technological improvements. For new homes, a projected savings of 40% is not unrealistic. This could be achieved by reduced glass area, heat pumps, design improvements, increased insulation, improved sealing and caulking, storm windows, etc. These savings would add up to 408,000 barrels per day in 1985.

The remaining residential energy savings include thermostat reductions (60°/65°) and increased air conditioner setting to a constant 78° -- 676,000 barrels per day; more efficient appliances -- 540,000 barrels per day; and increased lighting efficiency -- 80,000 barrels per day. Thus, the total residential savings are about 1.7 million barrels per day -- about the equivalent to the savings expected in the six major energy intensive industries. Table IX provides a breakdown.

OTHER

There are two further areas for significant energy savings -- electricity conversion and recycling and reuse. Today about two-thirds of the fuel used to generate electricity ends up as waste heat. But, the conversion efficiency has improved significantly in the past several years, and if this rate of improvement can continue, the savings by 1985 could reach 1.2 million barrels per day (Table X).

Recycling and reuse, e.g., burning solid waste, implementing returnable bottle legislation nationwide, and recycling of copper, aluminum and glass could add a further 643,000 barrel per day savings.

PUTTING IT ALL TOGETHER

Combining everything, we arrive at a savings -- as shown in Table XI -- of almost 10 million barrels per day by 1985 -- industry 2.8 million; transportation 2.8 million; residential 1.7 million; commercial .6 million; electric utilities 1.2 million, and recycling and reuse .6 million. This is more oil than the U.S. produced in 1974 and almost 60% of what we consumed in that same year. If we could achieve these savings, we would reduce our overall energy growth rate from 3.8% -- the long-term average -- to 2%.

These paper statistics, of course, are meaningless without total personal commitment from all of us. Utilities, their regulators and state and federal energy authorities all offer excellent shopping lists outlining energy conservation strategies for all sectors. These are usually available free of charge and furnish exhaustive hints on how the individual can reduce energy consumption and thereby contribute to the total energy conservation effort. Obviously, it would be impractical to attempt listing of these hints here.

In the final analysis it is the individual who will make or break this nation's energy conservation program. A poorly informed citizenry will be unable to make intelligent choices either in the energy marketplace or in public forums where a balanced energy policy must be hammered out.

The stakes are high. Indeed, the survival of our way of life as we know it is in the balance unless we can find a way to reduce our growing dependence on foreign oil supplies. Former Federal Energy Administrator John Sawhill gave this grave appraisal of just the economic implications:

> "At the present time, surplus funds of the OPEC nations--that is what they have left over after they have paid for imports and domestic development--are piling up at the rate of $60 billion a year. At this rate, 10 days worth of surplus OPEC cash is sufficient to buy the Bank of America; 79 days, the Exxon Corporation; 1.8 years, all of the America's direct investment outside of the U.S."

We would do well to heed Mr. Sawhill as well as the oft repeated advice of that great English playwright and novelist John Galsworthy who said, "If you do not think about the future, you cannot have one."

TABLE I

TRANSPORTATION SECTOR, WITHOUT CONSERVATION MEASURES

	1972	1985
Vehicle Miles Traveled	986,000 X 10^6 miles	1,300,000 X 10^6 miles
Fuel Consumption	4.77 X 10^6 bpd	5.39 X 10^6 bpd
Average Inertial Weight	3,854 lbs.	3,968 lbs.
Fuel Economy	15.3 mpg	15.7 mpg

TABLE II

NEW CAR SALES

	Standard	Intermediate	Compact
1958	90.2%	1.2%	3.2%
1972	38.3%	19.9%	13.1%
1985	11.0%	5.9%	33.1%

TABLE III

PROJECTED 1985 TRANSPORTATION SAVINGS

	Savings (M BPD)
Automobile Fuel Economy and Shift to Small Cars	1.83
Reduced Energy Needed to Produce Small Cars	.04
55 MPH Speed Limit	.11
Improved Efficiency of Intercity Freight Transportation	.23
Transportation Control Plans	.39
Increased Airline Load Factors	.16
	2.76

TABLE IV

ENERGY CONSUMPTION FOR VARIOUS INDUSTRIES

Industry	Energy Consumed Per $ of Value Added (MBTU/$)	% Manufacturing Consumption	Total U.S. Consumption
Cement	470	3.5%	.8%
Petroleum	330	11.6%	2.7%
Metals	117	18.6%	4.3%
Paper	112	10.1%	2.8%
Chemicals	94	21.1%	4.9%
Food	30	7.8%	1.9%
Total 6 Industries	94	72.8%	16.7%
All Other Industries	17	27.5%	6.3%
Total all Manufacturing	42	100.1%	23.3%

TABLE V

ENERGY CONSERVATION IN INDUSTRIAL SECTOR

	Growth Rate (%)	Equivalent Bpd Oil
Industrial Energy Consumption Without Conservation	3.9	0
Impact of Conservation in 6 Industries	3.2	1.7
Impact of Extending 6 Industrial Savings to Other Industries	2.9	.6
Impact of Extending One-half of 6 Industry Savings to Non-Manufacturing	2.6	.5
		2.8

TABLE VI

GROWTH IN COMMERCIAL SPACE AND ENERGY REQUIREMENTS

	1972	1985
Commercial Space (10^9 sq. ft.)	24	40
BTU's Consumed (10^{15})	5.4	10.3
Oil Consumed (10^6 bpd)	2.5	4.7

TABLE VII

POSSIBLE COMMERCIAL ENERGY SAVINGS

Action	Savings (M BPD)
Retrofit Existing Commercial Structures with Insulation	.1
Reduction of Energy Requirements in New Commercial Buildings	.39
Lighting Standards	.15
Total Savings	.63

TABLE VIII

RESIDENTIAL HOUSING PROJECTIONS

	1972	1985	Growth Rate %
Housing Units (10^6)	68.8	88.8	2.0
BTU's Consumed (10^{15})	12.5	17.4	2.5
Oil Consumed (10^6 bpd)	3.8	7.9	

TABLE IX

POSSIBLE RESIDENTIAL ENERGY SAVINGS

	Savings (M BPD)
Retrofit of Existing Homes with Insulation (etc.)	.408
Thermostat Reductions	.676
Energy Efficient Appliances	.540
Improved Lighting Efficiencies	.079
Total Savings	1.7

TABLE X

OTHER POTENTIAL SAVINGS (1985)

Action	Savings (M BPD)
Improved Electricity Conversion at 1.1% Per Year	1.1
Increased Use of Solid Waste to Generate Electricity	.35
Returnable Bottle Legislation (Oregon Model)	.24
Increased Recycling of Copper, Aluminum and Glass	.05
Total Savings	1.74

TABLE XI

TOTAL POSSIBLE ENERGY SAVINGS (1985)

	Savings (M BPD)
Industry	2.8
Transportation	2.8
Residential	1.7
Commercial	.6
Electric Utilities	1.1
Recycling and Reuse	.6
Total	9.6

Source - Tables I-XI:

Dr. John C. Sawhill, Stanford University/ Electric Power Research Institute (EPRI) Seminar, February, 1975

APPENDIX

Laws of Thermodynamics

The laws of thermodynamics are utilized to underscore operational "truths" in energy conversion efforts. An appreciation of the significant challenges awaiting man's efforts to devise improved energy systems will result if students understand the inflexibility of the parameters of the first and second laws.

The first "law" is a statement concerning the conservation of energy. Emphasized is the fact that regardless of the procedures or systems employed in the transformation processes energy is neither created nor destroyed. All of the heat energy introduced to a conversion system can be accounted for as mechanical work, friction, radiation, convection, etc. No energy is "lost".

The second "law" demonstrates that: (a) heat always flows from high to low temperature zones, (b) that heat cannot be transformed completely into work, and (c) some of the heat must always be rejected to a heat "sink" of lower temperature than the heat source.

GLOSSARY

A

AEC	Atomic Energy Commission.
absorbed dose	When IONIZING RADIATION passes through MATTER, some of its energy is imparted to the matter. The amount absorbed per unit mass of irradiated material is called the absorbed dose, and is measured in rems and rads.
activation	The process of making a material radioactive by bombardment with neutrons, protons, or other nuclear particles.
alpha particle (Symbol α)	A positively charged radioactive particle emitted naturally by heavy elements such as radium, thorium, uranium and plutonium.
alternating current	The alternate movement of current conducting electrons in opposite directions with no net displacement.
anaerobic	Occurring in the absence of air or oxygen.
atmosphere	The gaseous envelope surrounding an object. The earth's atmosphere consists of (approximately) 78% N, 21% O, 93% Ar, .03% CO_2, .04% other gases.
atom	A particule of matter indivisible by chemical means; it is the fundamental unit of the chemical elements. (One drop of H_2O contains approximately 6×10^{21} atoms.)
atomic number (Z)	The number of protons in the nucleus of an atom.
atomic weight	The atomic weight of any element is approximately equal to the total number of protons and neutrons in its nucleus.

B

BOD	A measure of the oxygen required to oxidize all of the organic matter in a body of water.
BTU	The quantity of heat required to raise the temperature of one pound of water one degree F.
BWR	A reactor which utilizes direct contact of the water moderator-coolant with the reactor core to develop steam.

background radiation	Naturally occurring nuclear radiation from cosmic rays, food, air, water and the earth.
barrel	Liquid volume equal to 42 U.S. gallons.
beta particle (Symbol β)	An elementary particle emitted from a nucleus during radioactive decay. A negatively charged beta particle is identical to an electron.
binding energy	Neutron or proton binding energies are those required to remove a neutron or a proton, respectively, from a nucleus. Electron binding energy is that required to remove an electron from an atom or a molecule.
boiling water reactor	A reactor in which water, used as both coolant and moderator, is allowed to boil in the core.
breeder reactor	A reactor that produces fissionable fuel as well as consuming it. The new fissionable material is created by capture in fertile materials of neutrons from fission.

C

calorie	The quantity of heat required to raise the temperature of 1 gram of water 1° Celcius.
capture	A process in which an atomic or nuclear system acquires an additional particle.
Celcius	Replacement of the name Centrigrade, a temperature scale based on the freezing (0°C) and boiling points of water (100°C).
chain reaction	A reaction that stimulates its own repetition. A fission chain reaction is self-sustaining when the number of neutrons released in a given time equals or exceeds the number of neutrons lost by absorption in non-fissioning material or by escape from the system.
char	The solid carbonaceous residue remaining from pyrolysis (incomplete combustion) of organic matter.
cladding	The outer jacket of nuclear fuel elements. Zirconium alloys are common cladding materials.
coal gas	A gaseous fuel produced by pyrolysis of coal. The energy, content is about 450 BTU/cu. ft.
condensation	The conversion of a vapor to a liquid.
containment vessel	A gas tight shell or other enclosure around a reactor.

continental shelf	Submerged land adjacent to continents where the water is less than 600 ft. in depth.
control rod	A rod, plate, or tube containing a material that readily absorbs neutrons (hafnium, boron, etc.).
coolant	A substance circulated through a nuclear reactor to remove or transfer heat.
cooling tower	A device for transferring heat to the atmosphere.
core	The central portion of a nuclear reactor containing the fuel elements and usually the moderator.
cosmic rays	Radiation of many sorts but mostly atomic nuclei (protons) with very high energies, originating outside the earth's atmosphere.
criticality	A state in nuclear materials where neutron losses and neutron generation are balanced.
crude oil (petroleum)	Petroleum liquids as removed from bearing strata. Also termed "crude."
curie	A measure of radioactivity. One curie (ci) is equal to 3.7×10^{10} disintegrations/sec.

D

decay, radioactive	The spontaneous transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide.
delayed neutrons	Neutrons emitted by radioactive fission products in a reactor over a period of seconds or minutes after a fission takes place. Fewer than 1% of the neutrons are delayed, the majority being prompt neutrons.
deuterium (Symbol ^2H or D)	An isotope of hydrogen whose nucleus contains one neutron and one proton and is therefore about twice as heavy as the nucleus of normal hydrogen. It occurs in nature as 1 atom to 6500 atoms of normal hydrogen.
direct current	A continuous flow of electrons through a conductor.
doubling time	The time required for a breeder reactor to produce as much fissionable material as the amount usually contained in its core plus the amount tied up in its fuel cycle.

E

ECCS	Emergency core cooling system.
ERDA	Energy resources development administration.
efficiency (ε)	The ratio of output to input of energy.
electrolysis	The decomposition of a compound into its elements achieved by passing a D.C. current through an electrolyte containing the compound.
electromagnetic radiation	Electric and magnetic waves that travel at the speed of light. Examples: gamma rays, X rays.
electron (Symbol e-)	An elementary particle with a unit negative electrical charge and a mass 1/1837 that of the proton. Electrons surround the positively charged NUCLEUS and determine the chemical properties of the atom.
electron volt (Abbrev. ev or eV)	The amount of kinetic energy gained by an electron accelerated through an electric potential difference of 1 volt. It is a unit of energy.
element	One of the 105 known chemical substances that cannot be divided into simpler substances by chemical means. A substance whose atoms all have the same atomic number.
energy	The capacity to perform work.
energy conversion	The transformation of one energy form to another.
exponential growth	A doubling of a value at regular intervals of time.

F

fast breeder	A breeder reactor utilizing neutrons in the "fast" energy range; ie., >100,000 ev.
fast neutron	A neutron with energy greater than approximately 100,000 electron volts.
fertile material	A material, not itself fissionable by thermal neutrons which can be converted into a fissile material by irradiation in a reactor. There are two basic fertile materials, uranium-238 and thorium-232.
fertile nucleus	A nucleus which serves as the neutron "target" in the generation of fissionable fuels.
fissile material	Any material fissionable by neutrons of all energies.

fission	The splitting of a heavy nucleus into two atoms of lower atomic weight and whose total mass is less than that of the original nucleus.
fission fragments	The two nuclei which are formed by the fission of a nucleus.
flux (neutron)	A measure of the intensity of neutron radiation. It is the number of neutrons passing through 1 square centimeter of a given target in 1 second.
fossil fuel	Any naturally occurring organic fuel, ie. coal, oil shale, petroleum, natural gas.
fuel cell	A device for direct conversion of chemical energy into electrical energy.
fuel element	A rod, tube, plate, or other mechanical shape into which nuclear fuel is fabricated for use in a reactor.
fuel pellet	For fusion reactors, a small pellet of frozen ^{2}D and ^{3}T.
fuel reprocessing	The processing of reactor fuel to recover the unused fissionable material.
fusion	The formation of a heavier nucleus from two lighter ones (such as hydrogen isotopes), with the attendant release of energy.

G

GCFBR	A fast breeder reactor cooled by gas.
gamma rays [Symbol γ (gamma)]	High-energy, short-wavelength electromagnetic radiation. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Similar to X rays, but are nuclear in origin.
gasification (coal)	Conversion of coal to a gaseous fuel.
geothermal energy	Heat energy available in the earth's crust.
greenhouse effect	The warming of the lower atmosphere by reradiation of solar energy.

H

half-life	The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form.
heat	A form of kinetic energy.

heavy water (deuterium)	Water in which the H atoms have been replaced by ^2H.
hydrocarbons	Compounds formed predominately of C and H with varying amounts of O, N and S.
hydrogen (Symbol H)	The lightest element, No. 1 in the atomic series. It has two natural isotopes of atomic weights 1 and 2. A third isotope, tritium, atomic weight 3, is a radioactive form produced in reactors by bombarding lithium-6 with neutrons.

I

ion	An electrically charged (+ or -) atom.
ionization	The addition or removal of electrons from atoms or molecules.
ionizing radiation	Any radiation displacing electrons from atoms or molecules, thereby producing ions. Ionizing radiation may produce severe skin or tissue damage.
isotopes	Atoms whose nuclei have equal numbers of protons but different numbers of neutrons.

K

Kelvin (K)	A temperature scale quantitatively equal to Celsius scale degrees but whose "zero point" reflects the point where no molecular motion exists.
kerogen	A heavy hydrocarbon of the general formula $(C_6H_8O)n$, the primary organic material of oil shale.
kilo	A prefix that multiplies a basic unit by 1000.
kilowatt (KW)	A power unit equal to 1000 watts/second.
kilowatt hour (KWH)	A measure of the energy expended or work performed by one KW acting for one hour.
kinetic energy	Energy due to motion, $E_k = 1/2\ mv^2$.

L

LNG	Liquefied natural gas (-161°C,-259°F) 600:1 volume reduction.
LPG	A mixture of gaseous hydrocarbons liquefied under pressure at normal temperatures. 2000-35000 BTU/cu. ft.

LOCA	Loss of cooling accident.
life index ratio (LIR)	The rates of reserves to production.

M

MHD	The generation of an electrical current by moving conductive gases through a magnetic field.
mass	The quantity of matter in a body. Often used as a synonym for weight, which, strictly speaking, is the force exerted by a body under the influence of gravity.
mass number (Symbol A)	The sum of the neutrons and protons in a NUCLEUS.
mega	A prefix that multiplies a basic unit by one million.
megawatt	10^6 watts.
Mev	One million electron volts.
micro	A prefix that divides a basic unit by one million.
milli	A prefix that divides a basic unit by one thousand.
moderator	A material used to control the rate of chain reactions.
molecule	A system of two or more atoms.

N

NEPA	Natural Environmental Protection Act, passed in 1970.
N.G.	A gaseous mixture of hydrocarbons, primarily methane (CHA).
nano	A prefix that divides a basic unit by one billion (10^9).
natural gas	A gaseous fuel frequently found associated with petroleum (wet N.G.) or may exist in non-associated deposits (dry N.G.). Contains 60-80% methane, plus ethane, propane, butane and other hydrocarbons. Average energy value is 1080 BTU/cu. ft.
natural radiation, natural radioactivity	= background radiation.
natural uranium	Uranium as found in nature, containing 0.7% of ^{235}U, 99.3% of ^{238}U, and a trace of ^{234}U.

neutron (Symbol n)	An uncharged elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen.
neutron capture	The process in which an atomic nucleus absorbs or captures a neutron.
nuclear energy	Energy released as electromagnetic radiation, as particulates and heat during reactions of atomic nuclei.
nuclear fission	The splitting of atomic nuclei into two or more sections.
nuclear fusion	The joining of small nuclei into a larger mass.
nuclear reaction	A reaction involving a change in an atomic nucleus, such as fission, fusion, neutron capture, or radioactive decay, as distinct from a chemical reaction, which is limited to changes in the electron structure surrounding the nucleus.
nuclear reactor	A device in which a fission chain reaction can be initiated, maintained, and controlled.
nucleon	An electrically neutral sub-atomic particle.
nucleus (atomic)	The central, most massive component of the atom, composed of both protons and neutrons but possessing a positive charge.
nuclide	A general term applicable to all atomic forms of the elements. The term is often erroneously used as a synonym for "isotope," which properly has a more limited definition. Whereas isotopes are the various forms of a single element, nuclides comprise all the isotopic forms of all the elements.

O

OPEC	Organization of Petroleum Exporting Countries.
oil shale	Sedimentary rock containing organic material (Kerogen) from which liquid petroleum can be extracted.
ozone	An unstable reactive molecule containing three atoms of oxygen.

P

PWR	A nuclear reactor utilizing water under pressure to ensure liquid contact of the coolant-moderator with all parts of the core and reactor components.
particulate	Existing as separate particles.

photochemical reactions	Chemical reactions energized by light, important to "smog" formation.
photon	The carrier of a quantum of electromagnetic energy.
photovoltaic cell	A type of semiconductor such as silicon or cadmium sulfide which, with the absorption of photons creates a separation of electrical charges and can produce a D.C. current of approximately 0.5 volts.
plasma	An electrically neutral gaseous mixture of positive and negative ions. Sometimes called the "fourth state of matter," since it behaves differently from solids, liquids and gases. High-temperature plasmas are used in controlled fusion experiments.
plutonium (Symbol Pu)	A heavy, radioactive, man-made, metallic element with atomic number 94. Its most important isotope is fissionable plutonium-239, produced by neutron irradiation of uranium-238.
poison	Any material of high absorption cross section that absorbs neutrons unproductively and hence removes them from the fission chain reaction in a reactor, decreasing its reactivity.
potential energy	Energy of position relative to another body.
potential energy reserve	Energy believed to be available.
power	The rate at which energy is utilized.
Price-Anderson Act (1957)	Insures owners of nuclear power plants against liability claims arising from nuclear accidents.
prompt neutrons	Neutrons that are emitted immediately following nuclear fission.
proton	An elementary particle with a single positive electrical charge and a mass approximately 1837 times that of the electron. Protons are constituents of all nuclei.
proven energy reserve	An energy source known to be available with existing extraction technology.
pyrolysis	The conversion of organic materials into other compounds via the use of heat in an Oxygen-deficient (O-free) environment. Principle products are gases, oils and char.

R

RBE	A measure of the specific biological effect produced by a given quantity of ionizing radiation.
rad	A unit of measurement of the absorbed dose of ionizing radiation.
radiation	The release of energy as electromagnetic radiation from atoms or molecules undergoing change.
radioactivity	The spontaneous decomposition of an unstable nucleus, usually accompanied by the emission of ionizing radiation.
radioisotope	A radioactive isotope. An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation. More than 1300 natural and artificial radioisotopes have been identified.
reactor	A device which regulates nuclear fission in a self-perpetuating chain reaction.
rem	(Acronym for roentgen equivalent man.) The unit of dose of any ionizing radiation which produces the same biological effect as a unit of absorbed dose of ordinary X rays. The RBE dose (in rems) = RBE x absorbed dose (in rads).
roentgen	A unit of measure of gamma or X radiation; the roentgen measures exposure, not absorbtion.

S

SNG	A fuel gas produced from naptha or coal. Energy value is 980 - 1035 BTU/cu. ft.
safety rod	A standby control rod used to shut down a nuclear reactor rapidly in emergencies.
slow neutrons	Low energy neutrons (thermal neutrons). The energy of a slow n $\approx$ 0.025 ev while fast neutrons exceed 1000 ev.
smog	Polluted air, primarily the results of atmospheric NO_x and CHO converted into other materials by sunlight.
solar cell	A device which converts solar energy to electrical current (D.C.).
sour N.G. or petroleum	Containing sufficient quantities of sulphur to be corrosive or offensive in odor.

spontaneous fission	Fission that occurs without an external stimulus. The process occurs occasionally in all fissionable materials, including uranium-235.
synthesis gas	A mixture of H and CO formed by reacting steam with hot char or coal. The energy content is approximately 250 - 350 BTU/cu. ft.

T

tar sands	Sedimentary materials containing various petroleum fractions which can be converted to oil.
thermal pollution	Adding heat to the environment.
thorium (Symbol Th)	A naturally radioactive element with atomic number 90 and, weight of approximately 232. The fertile thorium-232 isotope is abundant and can be transmuted to fissionable uranium-233 by neutron irradiation.
threshold dose	The minimum dose of radiation that will produce a detectable biological effect.
tritium (^3H or ^3T)	An isotope of H in which the nucleus contains one proton and two neutrons. Natural abundance of ^3H is $1:10^{17}$ of H.
turbine	A device which converts the kinetic energy of a fluid (or steam) to rotational (kinetic) energy.

U

uranium (Symbol U)	A radioactive element with the atomic number 92 and, as found in natural ores, an average atomic weight of approximately 238. Uranium is the basic raw material of nuclear energy.

V

volt	A unit of electric potential difference.
voltage	The difference of potential between two points measured in volts.

W

waste, radioactive	Equipment and materials (from nuclear operations) which are radioactive and for which there is no further use.
watt	A unit of power.

X

X-ray	A penetrating form of electromagnetic radiation. X-rays are always nonnuclear in origin.

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